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# THESIS

**DEVELOPMENT AND EVALUATION OF AN AUTOMATED DECISION AID FOR RAPID RE-TASKING OF AIR STRIKE ASSETS IN RESPONSE TO TIME-SENSITIVE TARGETS**

by

Paul R. Weaver

June 2004

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The thesis addresses the problem of optimally re-assigning strike aircraft to targets in response to the emergence of "pop-ups" or time-sensitive targets. The first part of thesis develops an automated decision aid to rapidly revise the current air tasking order (ATO), so as to: maximize achievement of target destruction goals (weighted by target priorities), minimize attrition risk to employed assets, and disrupt the current ATO as little as possible. The second part of the thesis develops a detailed test and evaluation plan to conduct a comparison of two competing automated decision aids and the current manual reassignment methods. Critical operational issues, measures of effectiveness and measures of performance were developed to fully evaluate operational performance. The time-sensitive-targeting decision aid was tested and validated during major air strike live exercises at Marine Aviation Weapons and Tactics Squadron One. Careful measurements comparing the re-taskings recommended by the decision aid against actual decisions demonstrated that in every case the model's solutions were of better or equal quality, maximized combat asset utilization, and were achieved significantly faster.

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**DEVELOPMENT AND EVALUATION OF AN AUTOMATED DECISION AID FOR RAPID RE-TASKING OF AIR STRIKE ASSETS IN RESPONSE TO TIME SENSITIVE TARGETS**

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## ABSTRACT

This thesis addresses the problem of optimally re-assigning strike aircraft to targets in response to the emergence of “pop-ups” or time-sensitive targets. The first part of this thesis develops an automated decision aid to rapidly revise the current air tasking order (ATO), so as to: maximize achievement of target destruction goals (weighted by target priorities), minimize attrition risk to employed assets, and disrupt the current ATO as little as possible. The second part of the thesis develops a detailed test and evaluation plan to conduct a comparison of two competing automated decision aids and the current manual reassignment methods. Critical operational issues, measures of effectiveness and measures of performance were developed to fully evaluate operational performance. The time-sensitive-targeting decision aid was tested and validated during major air strike live exercises at Marine Aviation Weapons and Tactics Squadron One. Careful measurements comparing the re-taskings recommended by the decision aid against actual decisions demonstrated that in every case the model's solutions were of better or equal quality, maximized combat asset utilization, and were achieved significantly faster.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ADT&E | Aviation Development, Tactics, and Evaluation (MAWTS-1) |
| AUX | Auxiliary |
| C2 | Command and Control |
| C3 | Command, Control, and Communications |
| COTS | Commercial Off The Shelf |
| COI | Critical Operational Item |
| EMI | Electromagnetic Interference |
| E-Test | Effectiveness Test |
| FINEX | Final Exercise |
| HQMC | Headquarters Marine Corps |
| JMPS | Joint Mission Planning System |
| MACCS | Marine Aviation Command and Control System |
| MARCORSYSCOM | Marine Corps Systems Command |
| MAWTS-1 | Marine Aviation Weapons and Tactics Squadron One |
| MCCDC | Marine Corps Combat Development Command |
| MEF | Marine Expeditionary Force |
| MISTEX | MACCS Integration Simulated Training Exercise |
| MMT | Marine Air Traffic Control Mobile Team |
| MOE | Measure of Effectiveness |
| MOP | Measure of Performance |
| MOS | Measure of Suitability |
| ORM | Operational Risk Management |
| QA | Qualitative Assessment |
| TBMCS | Theater Battle Management Core Systems |

| | |
|---|---|
| TCT | Time Critical Targets |
| TST | Time Sensitive Targets |
| WTI | Weapons and Tactics Instructor |

## ACKNOWLEDGMENTS

I wish to express my gratitude to those who contributed to the successful completion of this project. First, I would to thank Mr. Nick Gizzi, and Mr. John McDonnel from SPAWAR for their support and devotion to pursuing a solution to the problem facing tactical decision makers today.

My deepest gratitude goes to Professor Richard Rosenthal and Senior Lecture Thomas Hoivik, whose guidance has allowed me to develop a solution to a real world problem and demonstrate that it can have a significant impact outside of the laboratory.

To Mr. Anton Rowe, without your insight and unique talents the demonstration of this project in a tactical environment would not have been possible.

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## EXECUTIVE SUMMARY

The emergence of Time Sensitive Targets (TST) poses an imminent threat to friendly forces and the successful completion of the friendly commanders mission. Failure to decide and act within a short period of time, specified by a target's vulnerability window, results in loss of life or the disruption of a vital area.

The intent of this thesis is to provide the tactical decision maker with a fast and accurate automated decision aid that has been successfully demonstrated in a live tactical environment. The decision aid develops an appropriate aviation response to the emergence of a TST. There exists a multitude of systems that provide a commander with the necessary information to develop feasible courses of action. However, the determination of the best asset to assign to each target is done manually, and based solely on the experience of the decision maker.

The decision aid employs optimization techniques, and is an adaptation of the Davi Castro Model [2003] developed at the Naval Postgraduate School. The optimization model takes in all available resource information provided by the Air Tasking Order (ATO), to include; the number and type of aircraft, ordnance load, time window, and the aircrafts previously assigned task. Coupled with commander's guidance in the form of a prioritized list of targets, and assessment of the threat, the decision aid determines which asset to assign to each target within the vulnerability window. Options considered by the decision aid include: maintain the current plan, assign ground alert aircraft, divert airborne missions, or combine multiple mission assets against a single target. Assignments are made by weighting the terms of the objective function so as to consider with each assignment: target precedence, risk to aircrew, the number of required ATO changes, and available asset range.

In order to make a determination on whether or not this decision aid can support the needs of the commander a tactical evaluation was conducted at Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona. A

determination was made based on the results of the Critical Operational Issues (COI) listed below:

**COI 1. Target Selection.** The decision aid properly conducts target prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets.
**COI 2. Asset Availability.** The decision aid properly recognizes the assets that are available for a particular target.
**COI 3. Target Asset Pairing.** The decision aid properly recommends assets that have the ability to destroy the target.
**COI 4. Mission Risk Assessment.** The decision aid accurately assesses the risk of its proposed assignments.
**COI 5. Persistence.** The decision aid minimizes the number of changes to the ATO to achieve mission accomplishment.
**COI 6. Timeliness.** The decision aid provides a proposed solution fast enough to be effective when compared to current methods.
**COI 7. Options.** The decision aid did not provide the decision maker with multiple alternative solutions for mission re-tasking when available.
**COI 8. Tactical Accuracy.** The decision aids output provide tactically acceptable assignments.
**COI 9. Interoperability.** The decision aid operates correctly with the current C4I architecture.
**COI 10. Software Reliability.** The decision aid operates continuously without interruption or failure for a prolonged period of time.

Careful measurements comparing the re-taskings recommended by the decision aid against actual decisions demonstrated that in every case the model's solutions were of better or equal quality, maximized combat asset utilization, and were achieved significantly faster. The results of the evaluation lead to the determination of that ten of the eleven requirements were adequately met. Although positive comments were received in regard to Human Factors, no formal evaluation of this critical operational issue was performed.

The bottom line: NPS has produced a decision aid that can significantly improve the combat effectiveness against the emergence of a TST.

# I. INTRODUCTION

## A. PURPOSE

This thesis has two purposes. The first is to develop an automated decision aid to rapidly revise the current Air Tasking Order (ATO), so as to: (i) maximize achievement of target destruction goals (weighted by target priorities), (ii) minimize attrition risk to employed assets, and (iii) disrupt the current ATO as little as possible. The second purpose is to develop a detailed test and evaluation plan to conduct a multiple comparison of two automated decision aids, and the current manual reassignment methods employed by the Marine Aviation Command and Control System (MACCS). This test plan was executed during live exercises in April 2004 at Marine Air Station, Yuma, Arizona. In addition to the decision aid developed by the Naval Postgraduate School (NPS), the Rapid Asset Pairing Tool (RAPT) developed by the Space and Naval Warfare Command (SPAWAR) participated in the operational test. Critical operational issues, measures of effectiveness and measures of performance are developed to fully evaluate operational performance.

## B. BACKGROUND

### 1. Problem Statement

In today's military aviation command and control centers, decision makers are challenged with re-tasking previously assigned attack assets in response to the emergence of higher priority targets or changes in the tactical situation. This re-tasking must be conducted in a very short period of time so as to: achieve the required probability of kill, minimize the risk to aircrew from surface-to-air threats, and limit the amount of changes to the current ATO.

### 2. Time Sensitive Target (TST) Decision Making Practices

TSTs are "those targets requiring immediate response because they pose (or will soon pose) a danger, or are highly lucrative, fleeting targets of opportunity." [JP 3-60] Time-Sensitive Targeting is distinguished by the fact that it is purely reactive in nature. Predominantly, these targets are known to exist but are not yet located. Therefore, TSTs are not included in advanced planning

of missions, and need to be dealt with as soon as their locations are revealed. In contrast, the ATO is a product of a deliberate planning process. The majority of ATO assignments are preplanned aviation missions against known targets with known locations. The current ATO is the principle tool used in determining available resources necessary to contend with changes in the tactical scenario, such as the emergence of TSTs.

Systems currently employed to support assignment of aviation assets to targets of this nature focus on providing the decision maker situational awareness and a means to share information within the tactical data network. These systems are designed to support the approval process of a proposed asset assignment to strike the TST. The determination or selection of an asset is largely done by manual methods based on the experience of the command and control officer. The following is a general overview of the issues a command and control officer must consider when selecting an asset or assets for reassignment during the targeting phase of the TST process.

1. Available Resources. Decision makers require constant situational awareness to determine potential reassignment options
2. Weapons Effectiveness. The asset chosen by the decision maker to attack the target must be able to meet the specified destruction criteria.
3. Risk Assessment. A determination as to the vulnerability to each aircraft chosen to attack the target must be made. This is normally done in the form of a risk assessment based on the enemy's air defense capabilities. It is important to point out that, "Specific TSTs may be such a threat to the force or to mission accomplishment that the JFC is willing to accept a higher level of risk and attack the target immediately." [Commanders Handbook for Time Sensitive Targeting, 2002]
4. Associated Risks of Employment. This consideration is open to interpretation. This could imply the minimization of risk to friendly ground forces (fratricide), disruption of the current ATO, or minimization of collateral damage.
5. Method Selection. Of the options available, the decision maker must select the most appropriate platform considering all of the criteria previously mentioned.
6. Decision. Given the method selected, this task includes the approval of the method of attack, and the transition of a decision into action.[1]

[1] Multi-Service Tactics, Techniques, and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1, 2004

These techniques are developed through the education and training of our decision makers, who are in many cases brought in from military specialties other than command and control, predominantly aviators. The decision makers' knowledge of platform capabilities and the threat bring a tremendous wealth of experience to the role. The education and training provided by institutions such as MAWTS-1 focus this generic aviation experience into applied real-time decision-making.

## C. OBJECTIVES

There are two objectives of this thesis. The first objective is the development of a Time Sensitive Targeting Decision Aid that supports the needs of the decision maker in a real-time tactical environment.

The second objective is the development of a comprehensive test and evaluation plan to capture and assess whether or not the decision aids enhance the decision makers ability to conduct real-time re-targeting of aviation assets. The alternative approaches to be evaluated include:

a. Current manual assignment procedures based on military judgment and experience taught in the Weapons and Tactics Instructors (WTI) Course at Marine Aviation Weapons and Tactics Squadron 1.
b. The Rapid Asset Pairing Tool (RAPT), a genetic-algorithm based optimization tool under development by SPAWAR.
c. The integer-programming based optimization tool developed by Major Davi Castro and Prof. Richard E. Rosenthal of the Operations Research Department, Naval Postgraduate School.

## D. DECISION AID SUMMARY

Since 2001, the Space and Naval Warfare Command (SPAWAR) has been developing a decision aid to help reassign strike assets when high priority targets emerge during the execution of an Air Tasking Order. These time sensitive targets or "pop-up" targets, as they are known, represent a change in the tactical situation, which requires dynamic re-tasking of aviation assets. NPS started working on the same problem in 2002. Though SPAWAR and NPS use

different optimization modeling approaches inside their decision aids, both seek to assign aircraft and weapon loadouts to targets with the following objectives: achieve the required probability of kill, minimize the risk to aircrew from surface-to-air threats, and limit the amount of changes to the current Air Tasking Order (ATO).

The underlying approach in SPAWAR's decision aid is a genetic algorithm currently used in the Rapid Asset Pairing Tool (RAPT). [Louis,2003] On 3 October 2003, RAPT was demonstrated to Captain Heckert, Program Manager for Naval Mission Planning and Tomahawk Command and Control (PMA-281). The demonstration of RAPT's ability to quickly propose options in reassigning aircraft to higher priority targets was received with encouragement. SPAWAR was given the go-ahead to pursue current development with an emphasis on determining whether the results of the current system could be considered tactically accurate.

Assisting SPAWAR in development of a real-time decision aid for aviation assets is the Operations Research Department at the Naval Postgraduate School. Under the direction of Professor Richard Rosenthal, Major Davi Castro of the Brazilian Air Force developed an integer-programming based means to obtain a solution to the stated problem. In December of 2002, their work resulted in the Static and Dynamic Optimization Models used in assigning assets to a prioritized list of targets. For all intents and purposes, what was developed can be considered an ATO builder in its simplest form. Major Castro, even then, realized the potential for real-time asset allocation through re-optimization of an existing ATO. With further enhancements to his original Static Model for asset allocation, the ability to apply this model to real-time re-targeting is ready to be tested.

### E. SCOPE AND LIMITATIONS

The Weapons Tactics Instructors course provided a means to achieve the objectives of this thesis, however our evaluation was not the focus of MAWTS-1. Emerging high priority targets are part of the exercise scenario but may be limited in number. Additionally, the scenario is limited to operations in a desert

environment. Time Sensitive Targets that can emerge in populated areas are not be evaluated. The plan allows for the evaluation of human factors aspects of the decision aids. However, the decision aids were operated primarily by the developers, and therefore, it was not possible to conduct an effective evaluation of the human factors issues.

## F. THESIS ORGANIZATION

Chapter II provides a more detailed insight into Time Sensitive Targeting. Chapter III provides a description of the model developed by Major Castro, and the revisions made to adapt the model to a real-time tactical environment. Chapter IV discusses the development of the critical operational issues central to the evaluation. Chapter V provides a detailed analysis of data collected during the evaluation. Chapter VI provides conclusions and recommendations based on this analysis.

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# II. THE TIME SENSITIVE TARGETING PROCESS

## A. INTRODUCTION

The Time Sensitive Targeting Process consists of six phases: find, fix, track, target, engage, and assess. This chapter discusses each phase, with emphasis on Targeting, the phase in which the decision aids are employed. Figure 1[2], TST Process in Cyclical Form, provides a simple graphic outlining the phases of Time Sensitive Targeting and the tasks associated with each. A discussion of each of these tasks is the focus of this chapter and will provide the reader with the necessary background to understand the functioning of the decision aids presented in Chapter III.

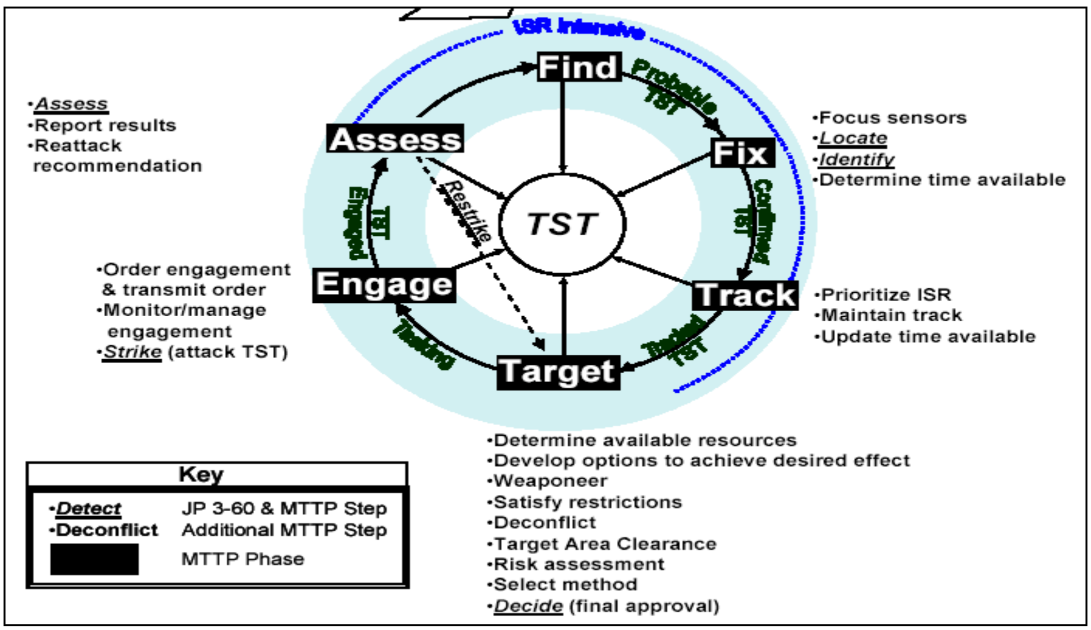


**Figure 1 The TST Process in Cyclical Form. Beside each phase of the process the tasks that must be performed are listed.**

[2] Time Critical Targeting Brief, Headquarters United States Air Force 2002

### 1. The Find Phase

TSTs are usually targets known to exist but have not yet been located. Therefore, the first task is to find them. The "find" phase, as referred to previously in Figure 3, receives the focus of all intelligence collection assets available on the battlefield. Assets used in finding TST's include, but are not limited to: Special Operations Forces (SOF), Airborne Collection assets (JSTARS, AWACS, and Strike Aircraft), and Space Based Collection Assets. Those individuals who are assigned the primary or alternate role of detecting TST's receive their direction from their commanders in various forms. The guidance and direction for TST's may come in a format as simple as a prioritized list as seen in the following example.

*"The adversary is known to possess, and has the capability to employ nuclear WMD against the Joint Force. Accordingly the following target types are designated Joint TSTs:*

- *Adversary activities deploying WMD from known storage areas.*
- *Known or suspected TBM with WMD payload." [Commanders Handbook for Time Sensitive Targeting,2002]*

On the other hand, the tools provided to assist in the detection of TSTs can be very specific, such as the following notional decision matrix depicted in Figure 2. The manual decision aid is used by operators throughout the battlefield, whose responsibility it is to assist in the prosecution of Time Sensitive Targets. This tool helps to clearly identify targets of this nature and provide guidance as to the appropriate responses to them. The first column lists the TST's in order of precedence. The second column describes the specific type of target to be found. The third column dictates who has the authority to approve the striking of that target. The fourth column denotes any special requirements in regards to striking the target. The fifth column denotes the acceptable level of risk for fratricide and collateral damage. The final column provides amplifying comments in regards to actions taken.

| Priority | TST Target Type | Desired Effect | Approval Authority | Additonal Restrictions | Accpetable Risk Level | Other Requirements or Notes |
|---|---|---|---|---|---|---|
| **JFC-1** | Weapon System A | Prevent Launch | On-Scene Flight Leader | ------ | Hi2 | Strike Immediately with any asset. Package recommended but will go without |
| **JFC-2** | Personel or groups meeting x criteria | Isolate, Capture, or kill | JFc or Above | Higher Level Notification required prior to striking | Hi | NotifyJFC immediately and maintain sensor track. Package recommended, threat dependent. |
| **JFC-3** | Critical Weapon System B | Prevent movement or use | JFC | | MED | Hazard Analysis required. Package Required |
| **JFC-4** | Critical Weapon System C | Neurtalize for campaign duration | TST Col Chief | ---- | LOW | SEAD Required |
| **JFACC-5** | Specific Key ground force/equipment movement | Destroy | JFACC | ----- | LOW | Convoy or military vehicles approaching phase line green |
| **JFACC-6** | Important weapon system D | Neutralize for campaign duration | TST Col Chief | ----- | LOW | SEAD Required |

**Figure 2 Notional TST Decision Matrix.**[3] **Depicts an example of a tool used by operators to help identify and determine the appropriate course of action for each TST.**

Once the process has been initiated with an emerging target the focus of this phase then becomes the determination of the target as one of four possible classifications. These classifications are: Probable TST, Non-TST, Unknown, or

[3] Multi-Service Tactics, Techniques, and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1,2004

not a target.[4] Each determination leads to one of four possible actions by the decision maker. Figure 3, Find Phase: Sequence of Conditions and Actions[5], provides the sequence just described and illustrates the four possible actions.

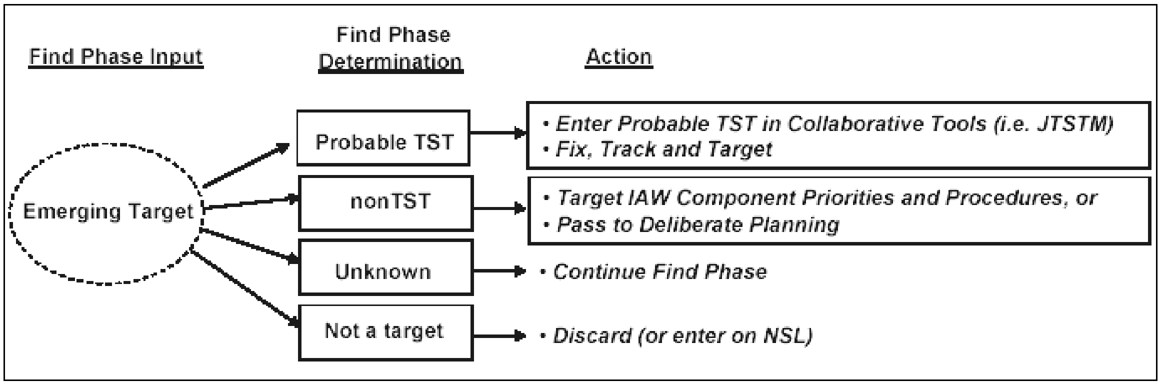


**Figure 3 Find Phase: Sequence of Conditions and Actions. Defines the sequence and events that occur beginning with the emergence of a target and concluding appropriate action given the determination of the target.**

The final output, or conclusion of this phase, is the nomination of a probable TST for further consideration. This in turn carries the target into the next phase of the TST process.

**2. The Fix Phase**

Once an emerging target is determined to be a probable TST , the process continues with the "fix" phase. This phase focuses on determining the precise location of the target. In this phase, data may be correlated from a variety of sources to confirm not only the location of the target, but that it is in fact a TST. Aside from a location determination, an additional product of this phase is the "vulnerability" window.[6] The task associated with the vulnerability window as depicted previously in Figure 3, is to determine the time available to conduct the

4 Multi-Service Tactics, Techniques , and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1,2004

5 Multi-Service Tactics, Techniques , and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1,2004

6 Multi-Service Tactics, Techniques , and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1,2004

strike. For fixed targets this window will obviously be larger than those that are mobile. There is no standard when it comes to the size of a vulnerability window. However, a brief presented in 2002 by Brigadier General Jim Morehouse, USAF, provided an excellent example of a vulnerability window for mobile TSTs. At that time, mobile Time Sensitive Targets were referred to as Time Critical Targets (TCT) by the United States Air Force. Figure 4, Phase Allotment Time,[7] below illustrates the vulnerability window with respect to mobile TSTs. In order for a decision maker to be effective against mobile time sensitive targets a proposed asset assignment must be made within 2 minutes.

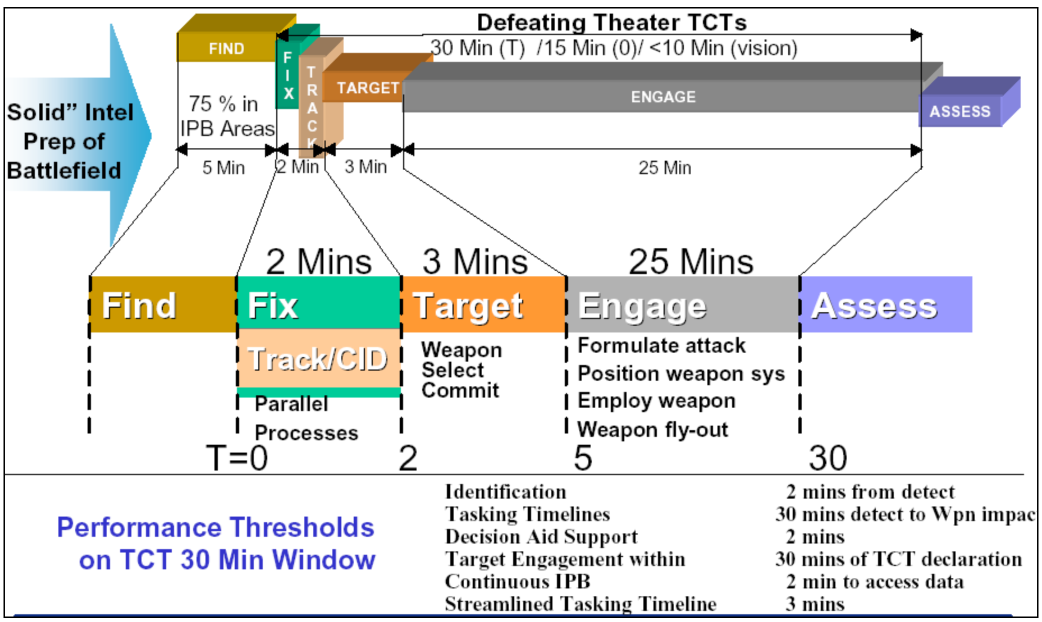


**Figure 4 Phase Allotment Time. Defines the time allotted to each phase within the TST Process.**

[7] Time Critical Targeting Brief, Headquarters United States Air Force 2002

### 3. The Track Phase

Prior to entering the "track" phase, the target has been confirmed as a TST and the location verified. This phase will continue until engagement has been completed.[8] It is important to the decision maker that situational awareness is maintained, and for this reason the coordination and focusing of additional battlefield sensors may be required.

### 4. The Target Phase

Although each phase within the process is of equal importance, the "Target" Phase is more adaptable to time saving decision aids, as will be discussed later in Chapter III. This phase, as depicted in figure 1, involves nine tasks that the decision maker must perform in selecting the most capable assets to address the target. These tasks include:

1. Determine available assets.
2. Develop options to achieve desired effects.
3. Weaponeer
4. Satisfy Restrictions
5. Deconfliction
6. Target Area Clearance
7. Risk Assessment
8. Select Method
9. Decide (final approval)

#### *a. Determine Available Assets*

Available resources are those assets, aviation or surface-to-surface fires, which can strike the TST within the designated vulnerability window. Aviation assets that may be considered available consist of the following: 1) aircraft not currently assigned to targets and assigned to an alert status, 2) aircraft currently assigned a target on the ATO that is of a lower priority, 3)

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[8] Multi-Service Tactics, Techniques , and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1, 2004

aircraft complete within current mission and have enough ordnance and fuel to accept a new assignment.

***b. Options That Can Achieve Desired Effects***

Of the assets available to conduct the attack on the TST, the decision maker must select the asset with the proper ordnance capable of achieving the desired effects. The list of available resources is therefore refined to increase the probability of success of the higher priority mission. This refinement process denotes the task, and develops options to achieve desired effects.

***c. Weaponeering***

For each TST, the commander provides a definition for the desired effects. For example, if the TST is a Multiple Rocket Launcher (MRL) Battery, and the desired effect is to destroy it, the commander defines what destroyed means. This could be stated as the number of launchers required to be rendered ineffective. To achieve these desired effects the decision maker conducts the task of weaponeering. Weaponeering is the process of determining the quantity of weapons, not just the weapon type, required to achieve desired effects.[9]

***d. Satisfy Restrictions***

In the next task, decision maker must verify any restrictions for attacking the target prior to engagement. Engagement restrictions vary with each target and are normally dependent on the precedence or value of the TST. These restrictions may include: 1) Collateral Damage Guidance, 2) Rules of Engagement, 3) Restricted Fire Areas, and 4) Fire Support Coordination Measures.[10] Restrictions established by the commander cannot be violated when striking the target.

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[9] Commanders Handbook for Joint Time Sensitive Targeting, 22 March 2002

[10] Multi-Service Tactics, Techniques, and Procedures (MTTP) for Time Sensitive Targets, FM 3-60.1, 2004

### *e. Deconfliction*

Deconfliction, denotes the coordination necessary to achieve safe and effective execution of the mission. The deconfliction of multiple aviation assets within a confined airspace requires detailed integration and cross component coordination.

### *f. Target Area Clearance*

The next task within this phase, Target Area Clearance, is simply a determination of whether or not the proposed asset for attack is permitted to strike in the location of the TST. This determination is made by the decision maker during the evaluation of the nominated target and is based on the decision makers approval authority given the geographic location of the target.

### *g. Risk Assessment*

Risk Assessment encompasses all associated risks of employment of a targeting solution. These risks include, but are not limited to: 1) risk of fratricide, 2) risk to attacking forces based on the threat, 3) risk to non-combatants, and 4) risk of disruption to the current plan.[11] All of these risks are weighed against the value assessed to the TST. These values vary, however; it is crucial to point out that "specific joint TSTs may be such a threat to the force or mission accomplishment that the Joint Force Commander is willing to accept a higher level of risk and attack the target immediately." [Commanders Handbook for Joint Time Sensitive Targeting, 22 March 2002]

### *h. Select Method*

The "target" phase continues with the selection of the strike asset by the responsible commander. It is the culmination of all previous tasks, and based on the vulnerability of the target will most likely have to be done in short period of time.

### *i. Decide*

The final task within the "target" phase is the decision made by the commander. This culminating point in the process should take approximately

[11] Commanders Handbook for Joint Time Sensitive Targeting, 22 March 2002

three to five minutes in duration and represents an approved action to be taken in response to the TST.

### 5. The Engage and Assess Phase

The TST process concludes with the “engage” and “assess” phase. The engage phase is the commander’s implementation of the decision. This phase involves contacting the assets selected and redirecting them from the original assignment. Once the assets are redirected and the attack has been conducted the success of the mission is assessed. If the desired effects are not achieved the process can begin again.

## B. CONCLUSION

The targeting phase of the TST process is of special importance to thesis. It is within this phase that the decision aid developed by NPS is applied. The discussions within this chapter provide the necessary background to understand the functioning of the decision aid presented in Chapter III.

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# III. OPTIMIZATION MODEL FOR RETASKING OF AIR STRIKE ASSETS

## A. INTRODUCTION

The model discussed in this chapter is a variation of the static optimization model previously developed by Major Davi Castro.[12] The new model optimizes the assignment of aviation assets to a prioritized set of targets over a short time horizon, taking into account the presence of surface-to-air threats. The performance of this model has been tested during live tactical exercises.

## B. PROBLEM DESCRIPTION

The problem addressed is the real-time re-tasking of aviation assets in response to a sudden change in the current tactical situation. The type of change for which the model is primarily intended is the emergence of a Time-Sensitive Target (TST) or “pop-up.” A TST is previously designated by the commander as a high-priority target, but its location is not known when the Air Tasking Order (ATO) is created. Therefore, TST’s are not included in pre-planned missions and need to be addressed after their locations are revealed.

The urgency of engaging a TST requires immediate tasking within its vulnerability window, as described in Chapter 2. The only assets available to engage the TST are those currently scheduled to perform other missions or to be in an alert status within the vulnerability window. The problem is then to assign these available assets to the TST and to the targets previously scheduled for attack in the vulnerability window. There is not enough time to get additional assets ready nor to reconfigure the ordnance of the available aircraft. Assigned aircraft must be available in the vulnerability window and capable of destroying their targets to the degree required within acceptable limits of attrition risk.

Time-critical conditions lead to a restricted set of options for assigning assets to targets. Each target included in this problem must be dealt with in one of the following ways:

[12] Optimization Models for Allocation of Air Strike Assets with Persistence, Davi Castro, 2003

1. Maintain the current plan. That is, for a non-time-sensitive target, use the assets already scheduled to attack it on the ATO. This would be the most convenient solution from a command and control perspective, but it may not be feasible for all targets due to the added demand of the TST.
2. Employ assets on alert status. This option would be the most convenient way to address the TST, provided the assets on alert are capable of attacking the TST with sufficiently high probability of success and low probability of attrition.
3. Redirect the assets of a previously scheduled mission to a different target. When missions are redirected, there is not enough time to reorganize the aircraft assigned to the previously scheduled mission into separate groups. All the assets of the previously scheduled mission must be kept together, whether or not their target changes.
4. Combine the assets of two or more previously scheduled missions and redirect them to a different target.

The right choice from among these options must be chosen for each target in less than three minutes of the emergence of a TST. Otherwise, friendly forces can be endangered.

If there are not enough available assets to strike every target, there may be some targets left unstruck within the vulnerability window. Priorities on targets are used to guide which ones are most important to strike. In solving this problem the objectives are to:

1. Maximize achievement of target destruction goals (weighted by target priorities).
2. Minimize attrition risk to employed assets.
3. Disrupt the current ATO as little as possible.
4. Minimize the distance traveled on the newly assigned missions.

These objectives are combined into one objective function with weights to insure that the first objective takes precedence over the second, the second over the third, etc.

The amount of target destruction achieved from the assignment of assets to targets depends on known probabilities of kill for each ordnance configuration against each target type. The attrition risk depends on known survival probabilities of each aircraft type against each air defense (AD) type, and if suppression of enemy air defense (SEAD) is used, it also depends on known suppression probabilities against the AD.

## C. SUPPRESSION OF ENEMY AIR DEFENSE

### 1. SEAD Increases the Number of Strike Options

In contrast to Major Davi's thesis, the model developed and tested here explicitly considers SEAD. SEAD assets, such as the EA-6B Prowler aircraft, are employed to neutralize the effectiveness of the enemy's AD threats, such as the SA-6 surface-to-air missile system. SEAD does not destroy these threats, instead it uses electronic means to render the AD's targeting systems ineffective.

A key idea of Davi's modeling is that candidate air strike packages are generated and evaluated against possible targets prior to optimizing for recommended assignments. An *air strike package* is a collection of aircraft and their associated ordnance loadouts, launched from a common airbase (or carrier), which can be assigned to a target. The feature of enumerating the possible package assignments prior to the optimization allows the nonlinear calculation of probabilities of kill and attrition to be handled efficiently within a linear optimization model. It also makes it easy to enforce constraints on allowable assignments. [See Davi, page 20, for details.]

The addition of SEAD to the modeling of the problem allows for the admissibility of more air strike packages than previously allowed. In Davi's work, the effectiveness of a strike package was computed based on what the survival probabilities for the aircraft in the package would be if they were engaged by the target's air defense threat. In some cases, the number of aircraft actually

reaching the target in the absence of SEAD would be diminished to the point that the package is ineffective and therefore not considered any further. Assigning a SEAD asset to accompany a package increases the survivability of the strike aircraft, thereby increasing the number of options that can be considered to strike the target.

### 2. "Man-to-Man" vs. "Zone" Defense

The employment of SEAD assumes that the SEAD asset can support only one mission at a time. The basketball analogy of "man-to-man defense" is used to describe this assumption. "Zone defense" would allow a SEAD asset to suppress threats for more than one mission, but this is not considered here. "Man-to-man" is consistent with current tactics. It is not assumed, however, that SEAD assets must remain with their supported assets after the strike. The SEAD may begin supporting another strike package before the strike aircraft in the previous package return to their base(s).

### 3. Implications and Assumptions of SEAD Employment

Due to the "man-to-man" assumption, a SEAD asset can be pre-defined as part of a strike package. The effectiveness and attrition probabilities of the strike packages can still be computed prior to optimization, preserving the computational advantages enjoyed by Davi's approach. The formulas used for these probabilities are given in Section D. They assume air superiority during the conduct of TST strike operations. Air superiority does not imply the absence of threat, but it does assume that aircraft striking a TST will not be countered with an overwhelming number of surface-to-air missiles.

The probability calculations assume that each threat system will fire one missile at each strike aircraft. This assumption is based on air superiority during offensive air support operations, and the existence of a degraded enemy air defense system. If the assumption were wrong and missiles outnumbered aircraft, the aircraft survival estimates would probably be optimistic.

The probabilities of survival and suppression included in the model runs reported in this thesis are unclassified and were provided by SPAWAR.

## D. OPTIMIZATION MODEL

This section provides the formulation of the optimization model developed and tested in this thesis.

### 1. Strike Package Eligibility

In Major Davi's models, any combination of aircraft and ordnance that pass muster with the judgment and experience of the strike planners can be considered for inclusion as a potentially recommended air strike package. For the time-critical situation considered in this thesis, there is far less freedom of choice. The aircraft and ordnance configurations as they appear on the current ATO are the only assets that can be considered. The only types of strike packages allowed are:

1. Air strike packages currently on alert status.
2. Air strike packages currently assigned to missions within the vulnerability window.
3. The union of the assets in two or more air strike packages of the first two types.
4. Air strike packages of the first three types with the addition of SEAD.

There is not enough time to break up the assets in a current mission into more than one air strike package. Nor is there enough time to reconfigure an available aircraft's weapons loadout, even if it takes a reconfiguration to achieve maximum effectiveness against the TST.

The time horizon for the problem treated in this thesis is too brief to allow using strike aircraft against more than one target. This is in contrast to the dynamic model in Chapter III of Major Davi's thesis. His dynamic model explicitly accounts for the time required to fly multiple missions, including the time between missions for reloading ordnance, refueling and making other necessary preparations.

### 2. Indices and Sets

The following section identifies all indices and sets used in the formulation of the optimization model.

j Targets requiring assignment (including one or more TST, and the targets currently scheduled on the ATO during the vulnerability window), e.g., {SS-21, T-72, Logistics Site,…}

m Missions currently scheduled on the ATO to either strike targets or stand on alert during the vulnerability window, { M1111, M1112,…}

n Available air strike packages, as explained in Section D.1 {N1,N2,...}

The resources to be allocated in this optimization model are the assets already assigned to the missions indexed by m. Some of these assets may continue to fly to their intended targets, while others may be re-tasked to a different target.

There are some situations in which two targets on the ATO are logically connected. For example, an SS-21 may be one target defended by another target, say, an SA-6. The destruction of the SS-21 cannot be achieved without destroying the SA-6. This relationship is identified in a pre-processing step and treated in the model by combining the two targets into one.

The following input data define important subsets of the index sets. They specify which targets may be struck by which packages and which missions' assets comprise which package.

nj(n,j) = 1 if target j can be assigned to air strike package n; 0 otherwise. This depends on whether the package has a sufficiently high probability of achieving the required destruction, and whether it can do so inside the vulnerability window and within an acceptable level of attrition risk.

nm(n,m) = 1 if air strike package n contains the assets of mission m; 0 otherwise.

### 3. Parameters

The data required to execute the optimization model are the penalty costs associated with assigning a particular strike package to a target, and the penalty cost for leaving it unstruck.

pen_nogo(j) = penalty for not striking target j

pen_attrition(n,j) = penalty for probable aircraft loss if strike package n is assigned to target j

pen_change(n,j) = penalty for causing changes in assets' target assignments if strike package n is assigned to target j

pen_distance(n,j) = penalty for aircraft travel distance if strike package n is assigned to target j.

The possibility exists that at the time a TST emerges, all assets may be assigned targets on the ATO. Although the ATO allows for aircraft to be in alert status without assignment to a dedicated target, this situation cannot always be relied upon. Even if there are aircraft in alert status, they may not have the necessary ordnance configuration to successfully engage the TST. In this case assets will be diverted to the TST, and some other target may go unstruck. The model seeks in this case to choose a low-priority target for non-assignment. If a previously assigned target becomes unassigned after re-tasking for the TST, then the unassigned target will be considered in a future run of the model.

These penalties are derived from raw problem data and the mission planner's judgment, as described in Section D.7.

### 4. Decision Variables

STRIKE(n,j) = 1 if air strike package n is assigned to target j, 0 otherwise

NOGO(j) = 1 if no strike package is assigned to target j, 0 otherwise

IDLE(m) = 1 if mission m is not used in any of the assigned packages, 0 otherwise

The STRIKE variables need to be treated as binary decision variables. The other two types of variables can be treated as continuous, since the

constraints will force them to take on binary values when STRIKE(n,j) are all binary. The variable IDLE(m) accounts for the possibility that the assets associated with a mission will not be needed for any of the current target assignments. The commander may choose to put these assets into the alert status.

### 5. Formulation

Minimize

$$\sum_{(n,j)\,:\,nj(n,j)=1} [\text{pen\_attrition}(n,j) + \text{pen\_change}(n,j) + \text{pen\_distance}(n,j)] * \text{STRIKE}(n,j)$$

$$+ \sum_{j} \text{pen\_nogo}(j) * \text{NOGO}(j)$$

s.t.

$$\sum_{n\,:\,nj(n,j)=1} \text{STRIKE}(n,j) + \text{NOGO}(j) = 1,\ \forall j$$

$$\sum_{(n,j)\,:\,nj(n,j)=1} nm(n,m) * \text{STRIKE}(n,j) + \text{IDLE}(m) = 1,\ \forall m$$

The first set of constraints ensures that each target is struck by at most one feasible, available strike package, or the target is left unstruck due to insufficient assets. Because the time horizon is so short, the second set of constraints ensures that the assets in each mission are employed at most once.

### 6. Given Data from which Parameters are Derived

Three additional indices are needed to specify the raw input data. They are not needed for the optimization model formulation because they are used only in calculations of parameters prior to the optimization.

a Aircraft types {FA18, EA6B,…}

r Threat types {SA6,SA8, …}

w Weapon types currently carried by missions on the ATO, {MK83, MK84,..}

The raw data for an instance of the problem consist of the following parameters:

| | |
|---|---|
| P_REQUIRED(j) | Commander's required probability of success for target j |
| SSP_KILL(w,j) | Single-shot probability of kill for weapon type w against target j |
| NUMAC(m) | Number of aircraft in mission m on the ATO |
| CONFIG(m,w) | Number of type w weapons loaded on each aircraft of mission m on the ATO |
| threat(j) | = r such that target j is known to be defended by a threat system of type r |
| SSP_SUPPRESS(r, w) | Single-shot probability of suppression of a threat of type r by a weapon of type w |
| actype(m) | = a such that mission m employs aircraft type a in the current ATO |
| SSP_SURVIVAL(r,a) | Single-shot probability of survival of an aircraft of type a when challenging a threat of type r |
| SSP_KILL(w,j) | Single-shot probability of kill for a weapon of type w against target j |
| PRIORITY(j) | Commander's priority for target j. (Smaller numbers mean higher priority) |
| PREV_ASSIGN(m,j) | = 1 if mission m is assigned to target j on the ATO, 0 otherwise. LAT(m), current latitude of the strike aircraft on mission m |
| LON(m) | Current longitude of the strike aircraft on mission m. |
| PRIORITY_WEIGHT, ATTRITION_WEIGHT, CHANGE_WEIGHT, DISTANCE_WEIGHT | Weighting factors for objective function terms |

### 7. Derivation of Probabilities and Penalties

Given the data provided in the previous section the following probabilities and penalties are derived prior to optimization.

#### *a. Probability of Suppression*

Probability of suppression is defined as the probability of successfully disabling the threat using package SEAD assets. It is calculated from the single shot probabilities of suppression of each SEAD weapon in the package. It uses an intermediate calculation of the weapon count for strike package n.

$$\text{NUMWEAPON}(n,w) = \sum_{m} \text{nm}(n,m) * \text{NUMAC}(m) * \text{CONFIG}(n,m)$$

$$\text{P\_SUPPRESS}(n,j) = 1- \prod_{w} (1- \text{SSP\_SUPPRESS}(\text{threat}(j))^{\text{NUMWEAPON}(n,w)} \quad \forall\ n,j$$

#### *b. Probability of Attrition*

Probability of attrition is defined as the probability of losing at least one aircraft from a package during a strike against a target. If there is no threat associated with a target, the probability of attrition is zero. If there is a threat associated with a target, the probability is calculated as the cumulative probability of SEAD assets failing to suppress the threat and the probability that at least one aircraft in the package fails to survive the unsuppressed threat.

$$\text{P\_ATTRITION}(n,j) = (1 - \text{P\_SUPPRESS}(n,j)) * (1 - \text{P\_SURVIVAL}(n,j))$$

#### *c. Probability of Survival*

Probability of survival of all aircraft in a package is calculated from the single shot probabilities of survival for each aircraft in the package against the given threat.

$$\text{P\_SURVIVAL}(n,j) = 1- \prod_{m\,:\,\text{nm}(n,m)=1} (1 - \text{SSP\_SURVIVAL}(\text{threat}_{(j)}, \text{actype}_{(m)})^{\text{NUMAC}(m)}\ ))$$

This method assumes a threat has the ability to take a single shot at each aircraft in the package. This is a worst-case scenario that can be used when there is incomplete information about how many weapons a threat may

have at-the-ready or in inventory and how quickly those weapons can be reloaded.

### *d. Probability of Kill*

Probability of kill is defined as the probability an air strike package can destroy a target ignoring the interference of any threats. It is calculated from single shot probabilities of all weapons in the package.

$$\text{P\_KILL}(n,j) = 1 - \prod_{w} (1 - \text{SSP\_KILL}(w,j))^{\text{NUMWEAPON}(n,w)} \;) \quad \forall n, j$$

### *e. Probability of Success*

Probability of success is defined as the probability of destroying a target without loss of aircraft. It can be computed from the probability of attrition and probability of kill.

$$\text{P\_SUCCESS}(n,j) = (1 - \text{P\_ATTRITION}(n,j)) * \text{P\_KILL}(n,j) \;\forall\; n,j$$

This computed probability is compared to the required probability of success for target j to decide if assigning package n to target j should become an allowable option in the optimization..

### *f. Penalty for Not Striking a Target*

The penalty for not striking *a target* is calculated by weighting a priority value that increases with higher priority targets. A priority exponent greater than 1 (usually 2) is used to accentuate the importance of top priority targets relative to lower priority targets.

$$\text{PEN\_NOGO}(j) = \text{PRIORITY\_WEIGHT} * (\, 1 / \text{PRIORITY}_{(j)} \,)^{\text{PRIORITY\_EXPONENT}}$$

### *g. Penalty for Losing an Aircraft*

The penalty for losing an aircraft in a strike is calculated by weighting the probability of attrition.

$$\text{PEN\_ATTRITION}(n,j) = \text{ATTRITION\_WEIGHT} * \text{P\_ATTRITION}(n,j)$$

#### *h. Persistence Penalty*

The persistence penalties for changing targeting assignments of strike aircraft are calculated by weighting the number of changes or "phone calls" required to implement the solution.

$$PEN\_CHANGE(n,j) = CHANGE\_WEIGHT * \sum_{m\,:\,nm(n,m)=1} (1 - PREV\_ASSIGN(n,j)) \quad \forall\ n,j$$

#### *i. Distance Penalty*

The distance penalty is calculated by weighting the nautical miles required for all aircraft in a package to reach a target.

$$PEN\_DISTANCE(n,j) = DISTANCE\_WEIGHT * \sum_{m\,:\,nm(n,m)=1} NUMAC(m) * DISTANCE(m,j) \quad \forall\ n,j$$

Distance can be calculated as the great circle distance between the two locations or obtained from mapping software if there are limitations on direct routes. In the case of the tactical evaluation discussed in Chapter IV, distances were ignored because they were judged to be too small to have a realistic impact on decisions.

### E. GRAPHICAL USER INTERFACE

With the help of the author, Mr. Anton Rowe, a research associate in the NPS Operations Research Department, we designed and built a spreadsheet-based graphical user interface (GUI) for the optimization model described above. The model is extremely easy to use with this GUI.

The principle interactive displays of the GUI are illustrated in Figures 5-7. Figure 5 shows the Target Screen, in which each target is listed with its priority, air defense threat (if any) and required probability of successful attack. There is an indicator field that specifies which targets are included in the current run of the model. In the example of Figure 5, the SS-21 on the bottom row is a TST.

## Targets

| Include | Target | Priority | Type | Threat | Probability of Success |
|---|---|---|---|---|---|
| x | TGT SA3 | 3 | SA3 | SA3 | 85% |
| | TGT 1 | 4 | Logistics Site | | 75% |
| x | TGT 2 | 5 | Logistics Site | | 75% |
| x | TGT 3 | 6 | Assembly Area | | 75% |
| | ZSU | 2 | ZSU | | 85% |
| | SA8 | 2 | SA8 | | 85% |
| | TEL | 2 | TEL | | 85% |
| x | SS21 | 1 | SS21 | | 85% |

**Figure 5 Target Screen. A screen shot provided by the model interface. It depicts all pre-planned and designated TSTs indicated by the far left column. The current threat associated with each target and the required probability of success are indicated in far right columns.**

Figure 6 displays the Mission Screen, which represents the current ATO. The missions selected on this screen are the ones whose assets are to be allocated in the optimization. For each mission, there is a call sign, times of departure and return, number and type of aircraft in the mission, weapon configuration, and the current ATO's target assignment. Pressing the "Recommend" button causes the optimization model to be generated and solved, with the resulting target assignments displayed in the right-most column. It generally takes about three seconds on a personal computer to obtain an optimal solution after about a minute or two of user input time. After the optimization model is solved, the Target Screen is updated as in Figure 7 to show the important results. These include the achieved probability of successful attack on each target and the probability of attrition for the assigned strike packages.

Missions

Recommend | Clear

| Include | Mission | C/S | ETD | ETR | # | Aircraft | Configuration | Assignment | Recommend |
|---|---|---|---|---|---|---|---|---|---|
| x | 6111 | Razor 11 | 15:51 | 17:07 | 2 | AV8B | [2] CBU58 | TGT SA3 | SS21 |
| | 6113 | Razor 13 | | | 2 | AV8B | [4] MK83 | TGT SA3 | |
| x | 6141 | Razor 41 | 15:51 | 17:07 | 2 | AV8B | [2] CBU58 | TGT 2 | |
| x | 6143 | Razor 43 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | TGT 2 | TGT 2 |
| x | 6115 | Razor 15 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | TGT 3 | TGT 3 |
| x | 6145 | Razor 45 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | SLA 15 | TGT SA3 |
| x | 6147 | Razor 47 | 15:51 | 17:07 | 2 | AV8B | [6] MK83 | SLA 15 | |
| x | 6161 | Razor 61 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | KB AA80 | KA AA80 |
| x | 6101 | Storm 01 | 16:19 | 19:09 | 2 | EA6B | [1] POD [1] HARM | TGT SA3 | TGT SA3 |
| | 6103 | Storm 03 | 16:19 | 19:09 | 1 | EA6B | [1] POD [1] HARM | TGT 2 | |
| | 6104 | Storm 04 | 16:19 | 19:09 | 1 | EA6B | [1] POD [1] HARM | SLA 30 | |
| | 6131 | Latch 31 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 1 | |
| | 6133 | Latch 33 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 1 | |
| | 6135 | Latch 35 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 3 | |
| | 6137 | Latch 37 | 17:04 | 18:24 | 2 | F18D | [4] MK83 | KB AA80 | |
| | 6175 | Latch 75 | 17:49 | 19:09 | 2 | F18D | [4] MK83 | KB AA80 | |
| | 6163 | Razor 63 | 18:07 | 19:21 | 2 | AV8B | [4] MK82 | SLA 15 | |
| | 6165 | Razor 65 | 18:22 | 19:36 | 2 | AV8B | [2] CBU58 | SLA 15 | |

**Figure 6 Mission Screen. The output from the interface of the model contains all the original ATO information. The left-most column indicates the available resources that will be the input to the model and reflect the assets currently available during the target's vulnerability window. In the top right hand corner of the display the "Recommend" Button can be seen. Selecting this button will run the optimization model and place the results in the far right column. The recommend column identifies all assignments to be made.**

**Targets**

| Include | Target | Priority | Type | Threat | Probability of Success | Probability Achieved | Probability of Attrition |
|---|---|---|---|---|---|---|---|
| x | TGT SA3 | 3 | SA3 | | 85% | 89% | 0% |
| | TGT 1 | 4 | Logistics Site | | 85% | | |
| x | TGT 2 | 5 | Logistics Site | | 85% | 93% | 0% |
| x | TGT 3 | 6 | Assembly Area | | 85% | 91% | 0% |
| | ZSU | 2 | ZSU | ZSU | 85% | | |
| | SA8 | 2 | SA8 | SA8 | 85% | | |
| | TEL | 2 | TEL | | 85% | | |
| x | SS21 | 1 | SS21 | | 85% | 89% | 0% |

**Figure 7 Target Worksheet. The target worksheet depicts each target included in the input to the model. For each target a priority and desired probability of success is provided. The column headed by "Probability Achieved" indicates for each asset assigned on the mission worksheet to a target, the desired probability of kill has been met.**

## E. Tactical Example

The problem illustrated in Figures 5-7 is an actual example from testing the model in live exercises at Marine Corps Air Station Yuma. The testing is described in detail in Chapters IV and V. As can be seen from Figure 7, the recommended solution is tactically accurate in the sense that every target is struck with the required probability of success. In this case, the model redirected a surprisingly large number of missions to different targets. This is in contrast to the solution obtained manually by the control group in the testing. Their solution involved no redirection because it engaged the TST with Mission 6145, which was on strip launch alert. The explanation of this initially disappointing result from the model was that it turned out that one of the current taskings on the ATO did not achieve the required probability of success. In this way, the optimization model identified a potentially dangerous mistake in the current ATO. This was an unintended benefit of using the new model. The next chapter describes the test plan for evaluating the new model in a live tactical exercise.

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# IV. TEST AND EVALUATION

## A. INTRODUCTION

Test and Evaluation is the "process by which a system or components are evaluated or compared against requirements and specifications through testing or experimentation. The results are evaluated to assess progress of design, performance, and supportability." [Test and Evaluation Lecture Notes, T.H. Hoivik, 2004] The test and evaluation of the decision aids developed by SPAWAR and NPS addresses the second objective of this thesis. This chapter explains the methodology developed and criterion used to support the evaluation of both the SPAWAR and NPS Decision Aids during a realistic tactical environment.

One problem in evaluating a new initiative or concept is determining precisely what the new initiative or concept is supposed to accomplish, matching the appropriate measures to determine if accomplishment has occurred, and identifying criteria for measurement of its overall worth. This thesis will utilize the Dendritic methodology[13] for deriving the decision aids critical operational issues, measures of effectiveness, measures of performance, data requirements, criteria for evaluation, and estimating the overall worth of these decision aid's.

Proper operational test designs are critical to identification and evaluation of factors that influence the new concepts worth. Otherwise, many so-called "tests" devolve into feasibility demonstrations and the resulting data and outcomes may not be credible or applicable for extension into real world situations. Unfortunately, the highly controlled and structured test methods used for accepting or rejecting hypothesis with a very high degree of certainty in <u>confirmatory</u> analysis do not apply to complex operational tests. Simply, there are too many variables to control and realism would be sacrificed. However, using select principles of test and experimental design in <u>exploratory</u> analysis, important insights into factors that effect or influence the worth of initiative or

[13] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik, Naval Postgraduate School, 2002

concept can be identified even though statistical significance may not be calculated.[14]

## B. DENDRITIC METHODOLOGY

The dendritic methodology is a process for deriving a system or concept's Critical Operational Issues (COI), Measures of Effectiveness (MOE), Measures of Performance (MOP), and Data Requirements (DR) for the purposes of operational test and evaluation or experimentation. Once data requirements are established, factors and conditions needed for appropriate evaluation can be identified and appropriate operational test scenarios or profiles can be generated for inclusion in the overall test.

The goal of the dendritic method is to identify relevant Measures of Performance (MOP) needed to analyze and evaluate performance (operational usefulness) of a specific concept, or initiative and to answer or resolve their associated operational issues. Since MOPs are usually rates, ratios, percents, or some quantitatively or qualitatively generated number, each MOP will define its required data elements.

The dendritic method starts by identifying all the functions and tasks that a specific decision aid is to perform. The most important decision aid functions and tasks will be transformed into operational issues (questions) that need to be evaluated (answered) during the experiment. The MOE for a decision aid generally relate to the capabilities desired for each function or task. Once MOEs have been identified, then appropriate quantitative or qualitative MOP (rates, ratios, percents, etc) can be developed to evaluate the effectiveness of each decision aid capability. It should be noted that several MOPs may be needed for each MOE and several MOEs are usually needed to fully encompass the evaluation of an experimental issue. With required and appropriate MOEs, mini-scenarios or run profiles, which are sets of factors and conditions, can be constructed to generate the required data. The test director while maintaining operational realism can insert these mini-scenarios or run profiles repeatedly,

[14] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik, Naval Postgraduate School, 2002

and at random, to foster efficient and credible data generation and comparative analysis. Therefore, even though the overall operational test may be complex and unstructured, the insertion of mini-scenarios or run profiles with appropriate systematic variation of the relevant factors and conditions will allow for enhanced analysis and evaluation. This will foster meaningful insight into, or identification of, those factors that influence the mission success or failure of a concept, process or decision aids. [15]

## C. CRITICAL OPERATIONAL ISSUES (COI)

First and foremost, to develop an effective evaluation the critical operational issues of the decision aids need to be determined. The dendritic method was used to develop the test plan used to evaluate the decision aids. The following is a summary of the process used to derive the COI's, MOE's, and MOP's derived to evaluate the decision aids. The first step in the dendritic method is to determine the decision aid's primary functions. The major capabilities desired for each function are then enumerated as shown in Table 1. These capabilities may then be subdivided into more specific capabilities if desired. This initial breakdown of functions and capabilities provides the basis for determining critical operational issues and system measures of effectiveness.

[15] Fundamentals for Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik, Naval Postgraduate School, 2002

| Function | Capability |
|---|---|
| **Target Selection** | Ensure target precedence is maintained during asset assignments |
| **Asset Availability** | Assignments are only comprised of assets that are able to strike the asset within the prescribed time. |
| **Target-Asset Pairing** | Method of attack that is selected must be able to achieve the prescribed destruction criteria. |
| **Mission Risk Assessment** | 1. Able to asses risk to multiple aircraft platforms from various surface-to-air threats<br>2. Assigns SEAD support when it is required. |
| **Persistence** | Limits the number of disruptions to the current ATO. |
| **Timeliness** | Determines solution in enough time to take effective action. |
| **Options** | Provides multiple courses of action. |
| **Tactical Accuracy** | Provides solutions that are acceptable in a live tactical environment. |
| **Interoperability** | Can receive Air Tasking Orders from current systems employed. |
| **Reliability** | Perform without interruption for 24 hours. |

**Table 1. Decision Aid Functions and Capabilities.**

COIs, are usually the critical functions a system must perform.[16] COI's provide the focus and direction for our test and evaluation. COI's are usually defined as questions to be resolved during the operational test. The COI's used in the evaluation of our decision aids are:

1. **COI 1. Target Selection.** Do the decision aids properly conduct target prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets?
2. **COI 2. Asset Availability.** Do the decision aids properly recognize the assets that are available for a particular target?
3. **COI 3. Target Asset Pairing.** Do the decision aids properly recommend targets that have the ability to destroy the target?
4. **COI 4. Mission Risk Assessment.** Do the decision aids accurately assess the risk of its proposed assignments?
5. **COI 5. Persistence.** Do the decision aids minimize the number of changes to the ATO to achieve mission accomplishment?
6. **COI 6. Timeliness.** Do the decision aids provide a proposed solution fast

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enough to be effective when compared to current methods?

7. **COI 7. Options.** Do the decision aids provide the decision maker with multiple alternative solutions for mission re-tasking when available?
8. **COI 8. Tactical Accuracy.** Do the decision aids output provide tactically acceptable assignments?
9. **COI 9. Interoperability.** Do the decision aids operate correctly with the current C4I architecture?
10. **COI 10. Software Reliability.** Can the decision aids operate continuously without interruption or failure for a prolonged period of time?
11. **COI 11. Human Factors.** Can the typical user enter inputs and understand the outputs in an efficient, intuitive manner with minimal training?

The following sections will describe each COI in detail, and justify their inclusion in the evaluation.

### 1. Do the decision aids properly conduct target prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets?

The senior commander establishes the priority of all targets on the battlefield and deviations from this can only occur with the consent of that commander. Targets are prioritized numerically beginning with one, the highest priority target. Given a situation where all assets are currently assigned, the potential for a target not being struck does exist. Each decision aid must be able to accurately assign assets so that the higher priority targets are paired with assets. Time Sensitive Targets are the highest priority targets on the battlefield; successful prosecution of these targets supercede all other priorities on the battlefield.

### 2. Do the decision aids properly recognize the assets that are available for a particular target?

Available assets are those that have not been cancelled on the ATO for mechanical failures and those that have not been committed to their original target and therefore are available for possible diversion. Current asset availability can be determined either manually or through automated updates received over the tactical data network. In either case each decision aid must be able to recognize changes in the status of the current ATO. This will allow each decision aid to properly determine the set of feasible solutions. The

determination of available resources is a target phase task that was previously identified in Chapter II.

### 3. Do the decision aids properly recommend targets that have the ability to destroy the target?

Each asset's ordnance effects against a given target type can be computed by the decision aids to estimate a level of destruction or probability of achieving the desired effect. This calculation must be equal to or greater than the destruction criteria required by the commander. Assets assigned that achieve the desired destruction criteria will be considered a correct assignment. This COI supports the following Target Phase tasks of (1) develop options to achieve desired effects, and (2) Weaponeer.

### 4. Do the decision aids accurately assess the risk of its proposed assignments?

Given a threat associated with a target, each decision aid is expected to compute a level of risk to the assets assignments. With regards to the decision aid, it is not the intent to discount or discard those assignment options that assume a high risk. It is, however, intended to display the risk associated with each potential assignment to the commander in order to make an informed decision. Based on this risk assessment a determination by the decision aid will be made to determine whether or not destruction criteria can be met or if SEAD assets are recommended to achieve desired effects.

### 5. Do the decision aids minimize the number of changes to the ATO to achieve mission accomplishment?

Each decision aid is expected to select an asset for assignment that causes the least impact to the existing plan. In developing a decision aid to be employed in a tactical environment, the number of re-assignments to be made and the effort required to implement the re-assignment must be considered. The impact to the ATO is measured by the number of radio calls required to redirect aircraft to their new assignments. The number of radio calls reflects the amount of coordination required to ensure safe and effective execution of the decision. Any redirection of aviation assets is a disruption; too many disruptions can result in an unsafe and eventually ineffective execution.

6. **Do the decision aids provide a proposed solution fast enough to be effective when compared to current methods?**

The timeline needed to generate a proposed solution, decide on the course of action, and then implement the decision is of the utmost importance. In Chapter II, Figure 4, a recommended timeline for decision tools to be effective in support of the TST process was identified. However, given a tactical environment, appropriate timeliness may be better determined by experienced decision makers. To resolve this COI a comparative analysis will be conducted to determine if there is a significant improvement in timeliness over existing manual methods.

7. **Do the decision aids provide the decision maker with multiple alternative solutions for mission re-tasking when available?**

There is no standard among decision makers to obtain a baseline for how a proposed assignment will be perceived in regards to the effectiveness, assessment of risk, or impact to the ATO. For this reason the number of options a decision aid provides allows for flexibility among decision makers. Decision makers may have different experiences or willingness to accept increased risk to achieve the desired end state. Therefore, the more options provided by the decision aids the more likely a proposed assignment will be accepted.

8. **Do the decision aids outputs provide tactically acceptable assignments?**

On a case-by-case basis the decision aids' proposed assignments will be evaluated for tactical acceptance. The assessment of this COI is qualitative in nature and for any given situation there can be multiple solutions that are acceptable. Not all of them necessarily need to result in the assignment of an aviation asset. For this reason a comparative analysis will not be conducted for this COI, rather the consistency of the decision aids to produce acceptable assignments will be evaluated for tactical acceptance regardless of whether or not they reflect the same course of action selected by the decision maker.

### 9. Do the decision aids operate correctly with the current C4I architecture?

Each decision aid, to be effective, has to either interact directly with existing decision aids that support the tactical data network or at a minimum recognize the data formats used by the ATO, Message Text Format (MTF). For each of the decision aids evaluated, the ATO provides all the information used in developing a proposed solution. Therefore the decision aid must be able to read the ATO in its existing format, otherwise access to this required information will not be possible.

### 10. Can the decision aids operate continuously without interruption or failure for a prolonged period of time?

Decision aid interruptions can occur for a variety of reasons, both external and internal. External factors such as power interruptions will not be credited against the reliability of the decision aids. However, given a consistent operating environment, all interruptions in the operation of the decision aids will be recorded and evaluated with respect to software reliability.

### 11. Can the typical user enter inputs and understand the outputs in an efficient, intuitive manner with minimal training?

Given the complexity of current command and control centers, such as the Tactical Air Command Center (TACC), a variety of decision aids employed by users place a premium on training to support usability of automated decision aids. With this in mind, any new decision aid has to be intuitive with regards to user interface. Operation of the decision aid interface will be evaluated throughout the test. Input/Output performance will be evaluated with respect to training requirements and personnel capabilities.

## D. MEASURES OF EFFECTIVENESS, MEASURES OF PERFROMANCE, AND DATA REQUIREMENTS

### 1. Introduction

The evaluation measures are critical to the assessment of the operational test. These measures express the level of success to which the desired outcomes are achieved. Both, MOE and MOP, will allow the results of each COI to be quantified and analytically compared in order to present a conclusion. Each COI can be resolved by a single or multiple MOEs and MOPs.

### 2. Measures of Effectiveness (MOE)

An MOE, is a measure which expresses the extent to which the system accomplishes or supports a mission or the task. MOE's are designed to address a COI. Each functional capability of the decision aids will help in identifying and defining the MOEs.[17]

### 3. Measures of Performance (MOP)

MOP, are a quantitative or qualitative measure of the system's capabilities or specific performance function. MOP's are usually in the form of rates, ratios, or percents.[18] Development of the MOPs using the dendritic methodology allows the operational test and evaluation of outcomes, either quantitatively or qualitatively. Quantitative MOPs will be used whenever possible. Quantitative measures, such as those used to evaluate the timeliness COI, will be compared based on a specified numeric measurement. However, due to the fact that there exists little formal criteria for the decision aids to be evaluated against, qualitative MOPs will be required for most of the performance measures. Qualitative measures, such as those used to evaluate the tactical accuracy COI, will be evaluated based on subjective measures determined by the user. There will be at least one MOP associated with each MOE. To meet the needs of the operational test MOP's, multiple data requirements have been derived to provide the necessary information to make the comparisons and resolve each COI.

### 4. Data Requirements

A test plan identifies what data requirements are needed and how they will be collected. The data requirements are necessary to compute each of the MOPs. In the case of this operational test plan, data requirements are recorded using data collection sheets and questionnaires. These documents along with a complete copy of the test plan appear in Appendix 2 of this thesis. A dendritic analysis can show the traceable relationship between COI's, MOE's, MOP's, and

[17] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik, Naval Postgraduate Scool, 2002

[18] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik, Naval Postgraduate School, 2002

data requirements. Figure 8 shows the dendritic analysis for the COI, Mission Risk Assessment and its relatable MOE's, MOP's, and Data Requirements.

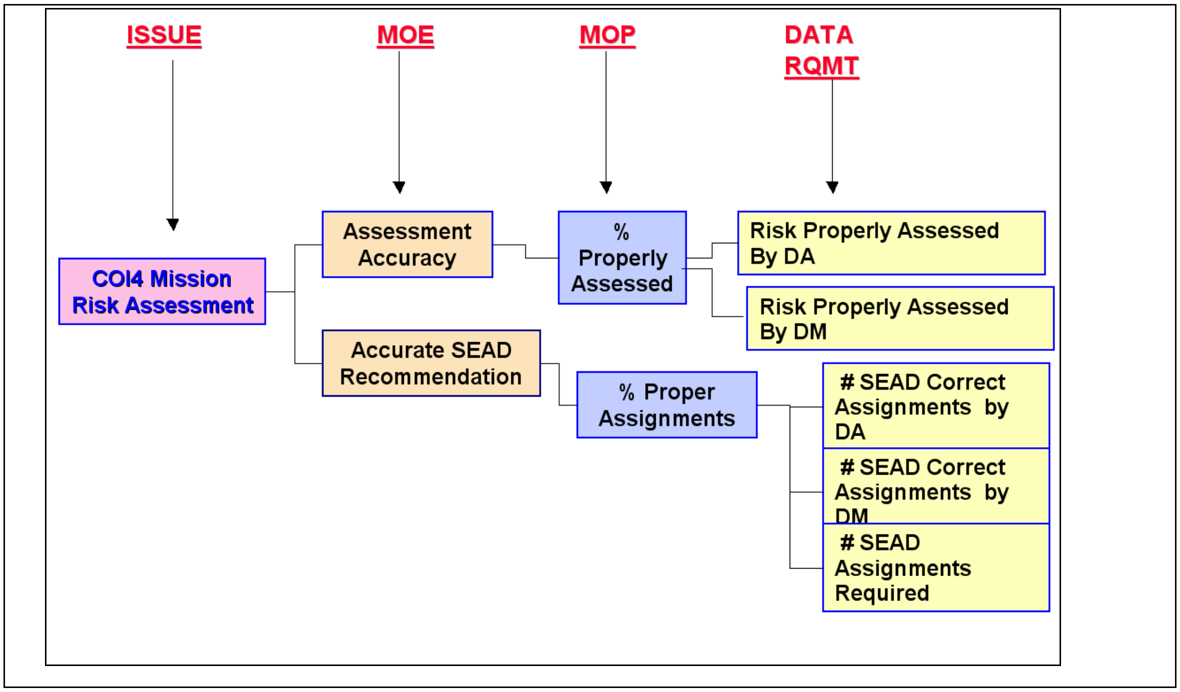



**Figure 8 Dendritic Method for COI, Mission Risk Assessment.**

## E. DECISION AID MOE'S, MOP'S, AND DATA REQUIREMENTS

In this section, for each COI, the appropriate MOE's, MOP's, and data requirements (DR) necessary to complete a quantitative or qualitative analysis of the decision aids as a whole will be discussed.

### 1. Do the decision aids properly conduct target prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets?

**MOE 1.1** - Accurate target selection. The MOE, accurate target selection, is accomplished, if during post decision analysis all targets of higher priority are assigned assets. Specifically, if all targets cannot be assigned assets, than those that remain unassigned are of lower priority.

**MOP 1.1.1** - Percent properly selected. The MOP will be to determine the proportion assigned without violating the established priorities of the targets.

**DR 1.1.1.1** – Total missions assigned.

**DR 1.1.1.2** - Number of missions not assigned with a higher priority by the decision aids.

**DR 1.1.1.3 –** Number of missions not assigned by decision maker (DM) without the aid of an automated tool.

**2. Do the decision aids properly recognize the assets that are available for a particular target?**

**MOE 2.1** - Asset availability accuracy. The MOE, accuracy of asset consideration, is defined by whether or not the proposed assignments consistently reflect those that are available for assignment. Knowledge of the assets that are available is dependent upon the accuracy of information available within the command and control centers. For this reason the assumption is made that the information within the TACC is both current and accurate.

**MOP 2.1.1** - Percent available considered. The MOP will be to determine the percent of aircraft missions proposed for assignment that are available.

**DR 2.1.1.1** - Number of aircraft available at the time target information is received.

**DR 2.1.1.2** - Number of aircraft assigned that were considered available and capable by the DM.

**DR 2.1.1.3** – Number assigned that were considered available and capable by the DM without the aid of an automated tool.

**3. Do the decision aids properly recommend targets that have the ability to destroy the target?**

**MOE 3.1** - Target Allocation Accuracy. The MOE, target allocation accuracy, is defined by whether or not the assets proposed for assignment have the ability to achieve the desired affects against the given set of targets. A correct target asset pairing for this MOE reflects the proper calculation of munitions effectiveness against the given target types. This evaluation was

conducted on the unclassified level so these values may not reflect the most accurate capabilities of the weapon system.

**MOP 3.1.1** – Percent Correct Assignments. The MOP is defined as the percentage of correct assignments. Assignments will be considered incorrect if a previously established probability of destruction is not met by the assignment. The data requirements necessary to conduct this assessment are:

**DR 3.1.1.1-** Number of assignments made by the decision aids that meet the destruction criteria.

**DR 3.1.1.1-** Number of assignments made by the DM that meet the destruction criteria.

**DR 3.1.1.2**- Total number of assignments proposed.

**4. Do the decision aids accurately assess the risk of its proposed assignments?**

**MOE 4.1** – Risk assessment accuracy. The MOE is defined by whether or not the level of risk depicted by the decision aids is accurate for each platform when a surface-to-air threat is associated with the given set of targets. The accuracy of the assessment is reliant on the known probabilities of kill for threat systems against various aviation platforms. Again, the values used to perform this assessment are on the unclassified level.

**MOP 4.1.1** – Percent properly assessed. The percent accurately assessed is qualitative in nature and a success will be determined by the MAWTS-1 Instructor during post event analysis. The data required to perform the assessment of the first MOP is:

**DR 4.1.1.1** - Computed risk assessment by the decision aids.

**DR 4.1.1.2** – Risk assessment by DM.

**DR 4.1.1.3** – Total number determined to be accurate.

**MOE 4.2**- Accurate SEAD recommendation based on risk assessment.

**MOP 4.2.1** - Percent of proper SEAD recommendations. The second MOP, SEAD recommendation, measures whether or not SEAD is proposed in addition to the asset target pairing given that it is determined necessary. The data required to conduct this assessment is:

**DR 4.2.1**- Number of SEAD assignments made when required by decision aids.

**DR 4.2.1** - Number of SEAD assignments made when required by the decision maker.

**DR 4.2.2**- Total number of SEAD assignments required.

**5. Do the decision aids minimize the number of changes to the ATO to achieve mission accomplishment?**

**MOE 5.1** - ATO Persistence. The MOE, ATO persistence, is defined as the level of impact the proposed assignments have on the current plan. The fewer the number of physical actions required by the decision maker the more desirable the solution.

**MOP 5.1.1** – Average number of changes. This MOP is the average number of changes required by each method. For each decision aid, the changes will be counted and compared to each other.

**DR 5.1.1.1** - Number of changes required per TST event.

**DR 5.1.1.2** – Number of TST events.

**6. Do the decision aids provide a proposed solution fast enough to be effective when compared to current methods?**

**MOE 6.1** - Decision Speed. The MOE, decision speed, is the time targeting information is received in the TACC until the decision aids provides output or the decision maker proposes a solution.

**MOP 6.1.1** - Average time of output generation. The average time of target info input and decision aid output. The following are a list of the data requirements needed to complete the calculations.

**DR 6.1.1.1** - Time from receipt of new target information by the decision aids or decision maker.

**DR 6.1.1.2** - Time of output determined by decision aids or recommendation on a particular course of action by the decision maker.

**7. Do the decision aids provide the decision maker with multiple alternative solutions for mission re-tasking when available?**

**MOE 7.1** - Multiple alternative generation. The single MOE for this issue, will allow us to compare each decision aid with each other and the decision maker to determine whether or not each method provides the decision maker with an acceptable number of proposed solutions.

**MOP 7.1.1** – Average number of alternatives per TST event.

**DR 7.1.1.1** - Number of alternatives recommended by the decision aids.

**DR 7.1.1.2** - Number of alternatives provided to DM.

**DR 7.1.1.3**- Number of TST events.

**8. Does the decision aid output provide tactically acceptable assignments?**

**MOE 8.1** - Probability of correct output is tactically acceptable. This MOE is qualitative in nature and the correctness of the proposed solution will be determined by MAWTS-1 instructors.

**MOP 8.1.1** – Percent output that is tactically acceptable.

**DR 8.1.1.1** – Number of acceptable assignments.

**DR 8.1.1.2**- Total number of assignments made.

**9. Do the decision aids operate correctly with the current C4I architecture?**

**MOE 9.1** - Probability of properly receive the ATO. The MOE will determine if the each decision aid can receive the basic information required to perform all necessary calculations. The inability to do this will not allow the decision aids to operate.

**MOP 9.1.1** - Percent of ATOs received properly.

**DR 9.1.1.1** - Number of Air Tasking Orders properly received and interpreted by the decision aids.

**DR 9.1.1.2** - Number of Air Tasking Orders.

**10. Can the decision aids operate continuously without interruption or failure for a prolonged period of time?**

**MOE 10.1** – Reliability. The MOE will help determine if the decision aids can perform during sustained operations without interruption. A final determination for this COI will not be attained during this test alone. The maximum length of each tactical evolution will be 8 hours.

**MOP 10.1.1** – Mean time between failure. The MOP will be calculated by dividing the total time of operation by the number of internal failures. The types of failures will also be recorded.

**DR 10.1.1.1** – Total time.

**DR 10.1.1.2** - Number of failures.

**DR 10.1.1.3** - Types of failures.

**11. Can the typical user enter inputs and understand the outputs in an efficient, intuitive manner with minimal training.**

**MOE 11.1** – Interface usability. The MOE will be evaluated qualitatively with questionnaires and interviews.

**MOP 11.1.1** - Percent operators satisfied with the interfaces.

**DR 11.1.1.1** – Number satisfied with the probability of destruction display.

**DR 11.1.1.2** - Number satisfied with the risk assessment display.

**DR 11.1.1.3** – Number satisfied with the persistence measurement display.

**DR 11.1.1.4** – Number satisfied with the current mission number display.

**DR 11.1.1.5** – Number satisfied with the ordnance capability display.

**DR 11.1.1.6** - Number satisfied with the display regarding the previously assigned target, its priority, and associated threat.

**DR 11.1.1.7**- Number satisfied with the display regarding the new target and its priority and associated threat

**DR 11.1.1.8** – Total number of operators

## F. CRITERIA

### 1. Introduction

The operational test criteria are expressions of the operational level of performance of the decision aids required by the typical user personnel to demonstrate mission effectiveness for specific functions during each test. The test criteria are not pass/fail conditions, rather, they represent a baseline for use in the design and evaluation for the operational test. In applying the test criteria to technical initiatives, it should be kept in mind that ultimately performance should be achieved in a realistic operational environment. [19]

Without the aid of, a specific quantitative requirement, or criteria for comparative analysis, an effective evaluation of the decision aids is very difficult. The decision aids are being evaluated without any formal criteria established. With this in mind, evaluating the overall worth of the decision aids are limited to: 1) comparison to manual TST methods previously discussed in chapter two, 2) a pairwise comparison of the decision aids developed by SPAWAR and NPS with respect to the COI's, MOE's, and MOP's.

### 2. Test Criteria

The criterion for this operational test is first the comparative analysis between the results produced by the decision aids and the manual methods of assigning assets to TST's in a live tactical exercise. The agency asserting the manual methods during this process is the Marine Tactical Air Command Center (TACC). During the operational test the TACC will be manned by qualified Marine personnel experienced in the Time Sensitive Targeting process. Each TST event will provide data for comparative analysis between the output of each of the decision aids and the manual output.

[19] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas H. Hoivik

The second criteria, pairwise comparison, will be a quantitative and qualitative analysis of the two decision aids developed by SPAWAR and NPS. The comparison will be conducted over each TST event to explore differences and advantages of each decision aid.

## G. GENERAL TEST OPERATIONS AND OPERATIONAL SCENARIO

### 1. Introduction

The development of test scenarios, segments, and trials, is the next step in the test planning process. Although overarching scenarios will vary from Service to Service and test to test, it is the segmenting and structuring of various segments and trials (within the scenario) to identify factor effects that are most important.[20]

The overall test should be concept driven. That is, it needs to reflect the test objectives that answer or resolve the critical operational issues for the decision aids. As it pertains to this evaluation, the test needs to reflect realistic TST events in a threat environment. Each of these events is designed to foster appropriate decision making in response the TSTs in a tactical environment.

The tradeoff is between controlling scenarios where some realism is lost, and having total freeplay occur where factor confounding will significantly limit evaluation capability.[21] The exercise control group, or white force, when executing the overall operational scenario, will provide the method of control. The white force can systematically vary factors and conditions within TST events without the TACC knowing and introducing bias. In developing these TST events, some factors may be held constant and others varied for each TST. This will allow better identification and analysis of factors that have an important influence on mission accomplishment, such as the presence of surface-to-air weapons systems.

[20] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas Hoivik, Naval Postgraduate School, 2002

[21] Fundamentals of Military Experiment Planning, Design and Analysis, by Thomas Hoivik, Naval Postgraduate School,2002

### 2. Evaluation and Scenario Description

The evaluation was conducted during the Weapons Tactics Instructor's Course (WTI) 2-04. The course is executed by Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) located at Marine Corps Air Station (MCAS) Yuma, Arizona. The tools and methods to be evaluated will be located in the Marine Tactical Air Command Center (TACC). The TACC is the senior aviation command and control agency for the Marine Corps and is ultimately responsible for the conduct of the air war, to include real time re-tasking of aviation assets. WTI is designed to train and evaluate the Marine Corps experienced Aviators, Command and Control Officers, and Aviation Ground Support Officers in the conduct of their assigned specialties. Once training is complete the officers and enlisted personnel are sent back to their units to become the resident experts for the unit. Within the Marine Corps aviation community, WTI has been referred to as a "graduate level course for tactics."

The execution of a WTI course presents a unique opportunity to evaluate not just our Marines, but the tools developed to support the conduct of their mission. The course is divided into two phases: Academic and Flight. The flight phase of the course provides the vehicle for this evaluation.

During the flight phase the evaluation focuses on only two separate flight phase evolutions. The MACCS Integrated Simulated Training Exercise (MISTEX), and the Final Exercise (FINEX) will comprise the specific test vehicles for the evaluation.

MISTEX is a static exercise consisting of the entire Marine Aviation Command and Control Decision aids in the field executing a realistic, low intensity, tactical scenario over a two-hour period. This MISTEX scenario is executed twice over a two-day period to ensure the MACCS is fully operational prior to the beginning of flight operations.

FINEX is the culminating exercise of the WTI course. It is highly intensive and demonstrates all six functions of Marine Aviation. These six functions include Control of Aircraft and Missiles, Anti-Air Warfare, Offensive Air Support,

Assault Support, Air Reconnaissance, and Electronic Warfare. The functions are driven by a tactical scenario where command and control officers are exercising their delegated authority in the direction and control of aircraft. The determination of whether or not the decision aids can adequately support the decision makers in this type of operation was assessed during this evolution.

The scenario, for the purposes of the evaluation, consists of offensive and defensive combat operations involving ground and air forces against a heavy mechanized division in a desert environment. The enemy air capabilities consist of two air force groups with a mixture reconnaissance, anti-air, air to ground, and support capabilities. In addition, a major consideration of the friendly forces was the enemy's surface-to-surface, and surface to air missile threat. The phase of the operation in which the decision aids are evaluated primarily involved offensive air support and assault support operations. The general description of the enemy's capabilities provide the source of targets and threats for evaluation of the decision aids. The enemy forces are simulated on the ground either through the use of static targets or electronic threat emitters. Friendly aviation support, command and control, and air defense forces used in the execution of this scenario was live. Friendly ground combat forces will be represented by, one USMC infantry company, and one USMC Artillery battery. There will be no notional/simulated friendly aircraft during the execution of the flight phase. The MAWTS-1 Test Plan document is include in Appendix 2 of this thesis.

#### 3. Data Recording

The results, for each event, will be collected by test personnel. Test personnel are separate and distinct from the operational force. The data was compiled using questionnaires and data collection sheets as shown in the MAWTS-1 Test Plan, Appendix 2. The results and analysis of the operational test are presented in Chapter V.

#### 4. Operating Forces

The operational force directly relating to the evaluation is representative of Marine Air Command and Control System, approximately 900 Marines. The

representative air wing, which supports all aviation operations within the scenario, provides approximately 100 daily aviation sorties.

# V. RESULTS AND DISCUSSION

## A. INTRODUCTION

On April 16, 2004, the test and evaluation of the decision aid concluded with the completion of the FINEX 3 evolution of the Weapons Tactics Instructors Course (WTI). During the five flight phase evolutions; MISTEX 1, MISTEX 2, FINEX 1, FINEX 2, and FINEX 3, twenty three Time Sensitive Targets emerged as part of the tactical scenario. Detailed data with respect to the COI's discussed in Chapter IV were collected with the exception of COI 11, Human Factors, due to the high tempo of exercise operations.

Originally, it was the intent of the evaluation to compare the results of the SPAWAR's genetic algorithm. Unfortunately, due to software difficulties their decision aid was unavailable to be evaluated adequately.

The following sections of this chapter provide the answers to each question posed by the COI's provided in the test plan.

## B. COI 1: TARGET SELECTION. DO THE DECISION AIDS PROPERLY CONDUCT TARGET PRIORITIZATION OF TARGETS TO ENSURE MISSION ACCOMPLISHMENT OF HIGHER PRIORITY TARGETS BEFORE LOWER PRIORITY TARGETS?

This COI addresses the ability of the decision aid to properly conduct target prioritization by assigning assets to only the highest priority targets. During each evolution a prioritized target list was provided. During the MISTEX evolutions the predominant number of ATO assignments were a pre-planned mission against prioritized targets. However, during the FINEX evolutions the majority of air missions were in general support and on alert status. A violation or miss-assignment as identified in Table 1 occurs if:

1. A TST was ignored, and not assigned an asset.
2. Of the set targets addressed during the time horizon defined by the TST's vulnerability window, a higher priority target was left unassigned.

Table 2, provides all data obtained with respect to this COI.

| | COI #1 Target Selection | | | | |
|---|---|---|---|---|---|
| | TST | # of Targets left unassigned that have higher priority than those assigned | | | |
| | | NPS | | DM | |
| | | Miss-Assign | Total Assign | Miss-Assign | Total Assign |
| MISTEX 1 | 1 | 0 | 3 | 1 | 0 |
| | 2 | 0 | 1 | 0 | 1 |
| | 3 | 0 | 1 | 0 | 1 |
| | 4 | 0 | 1 | 0 | 0 |
| | 5 | 0 | 1 | 0 | 2 |
| | 6 | 0 | 1 | 0 | 2 |
| MISTEX 2 | 7 | 0 | 3 | 1 | 1 |
| | 8 | 0 | 1 | 0 | 1 |
| | 9 | 0 | 2 | 1 | 2 |
| | 10 | 0 | 1 | 0 | 1 |
| | 11 | 0 | 1 | 0 | 1 |
| Finex1 | 12 | 0 | 1 | 0 | 0 |
| | 13 | 0 | 2 | 0 | 1 |
| | 14 | 0 | 1 | 0 | 0 |
| Finex 2 | 15 | 0 | 1 | 0 | 0 |
| | 16 | 0 | 2 | 0 | 1 |
| | 17 | 0 | 2 | 0 | 0 |
| | 18 | 0 | 2 | 0 | 0 |
| Finex 3 | 19 | 0 | 1 | 1 | 0 |
| | 20 | 0 | 1 | 0 | 1 |
| | 21 | 0 | 3 | 0 | 0 |
| | 22 | 0 | 1 | 0 | 1 |
| | 23 | 0 | 1 | 0 | 1 |

**Table 2 COI 1, Target Selection. Depicts the data required to determine percentage of target selection done accurately.**

Based on the data collected the NPS Decision Aid provided accurate target selection 100%(34/34) of the time. By comparison the decision maker accurately selected the targets to be assigned assets 76 % (13/17) of the time. The difference in TST events between the decision aid and the decision maker is

the result of one of the following reasons: target location was not accurate, or the target was mistakenly not assigned an asset. Of the miss-assignments that occurred the following are cited as examples. In the first TST, the decision maker chose to ignore the target and execute the ATO as planned. In the seventh TST, occurring during MISTEX 2, the decision maker diverted a mission assigned to a target of priority 3, while an asset on ground alert remained available with the capability to destroy the target. In some cases the decision maker made no assignment. This action did not count for or against the decision maker, because it indicates an option selected other than an aviation asset.

Within the scope of the evaluation it was determined that when given a prioritized list of targets the NPS Decision Aid does accurately select targets for assignment as required by COI 1. It is recommended that no changes be made to the model with respect to target selection.

### C. COI 2: ASSET AVAILABILITY. DO THE DECISION AIDS PROPERLY RECOGNIZE THE ASSETS THAT ARE AVAILABLE FOR A PARTICULAR TARGET?

The COI addressed the decision aids ability to select assets available for assignment. An asset not available falls into to one of the following categories:

1. Asset canceled on the ATO due to mechanical problems.
2. Asset that has proceeded to target.
3. Asset that is not under control of the component reassigning it.

Availability is based on the accuracy of the information within the TACC. If the information available to the decision maker and the decision aid is inaccurate, neither are be held accountable for a proposal based on the available information. Table 3, depicts the data obtained from the proposals made by the decision aid and the decision maker.

| | COI #2 Asset Availability | | | | |
|---|---|---|---|---|---|
| | TST | # of Selceted for assignment that were unavailable | | | |
| | | NPS | | DM | |
| | | #Unavail | Total Assign | # UnAvail | Total Assign |
| MISTEX 1 | **1** | 0 | 3 | - | - |
| | **2** | 0 | 1 | 0 | 1 |
| | **3** | 0 | 1 | 0 | 1 |
| | **4** | 0 | 1 | 0 | 0 |
| | **5** | 0 | 1 | 1 (GCE FAC(a)) | 2 |
| | **6** | 0 | 1 | 0 | 2 |
| MISTEX 2 | **7** | 0 | 3 | 0 | 1 |
| | **8** | 0 | 1 | 0 | 1 |
| | **9** | 0 | 2 | 0 | 2 |
| | **10** | 0 | 1 | 0 | 1 |
| | **11** | 0 | 1 | 0 | 1 |
| Finex 1 | **12** | 0 | 1 | 0 | 0 |
| | **13** | 0 | 2 | 0 | 1 |
| | **14** | 0 | | 0 | 0 |
| Finex 2 | **15** | 0 | 1 | 0 | 0 |
| | **16** | 0 | 2 | 0 | 1 |
| | **17** | 0 | 2 | 0 | 0 |
| | **18** | 0 | 2 | 0 | 0 |
| Finex 3 | **19** | 0 | 1 | 0 | 0 |
| | **20** | 0 | 1 | 0 | 1 |
| | **21** | 0 | 3 | 0 | 1 |
| | **22** | 0 | 1 | 0 | 1 |
| | 23 | 0 | 1 | 0 | 1 |

**Table 3. COI 2, Asset Availability, depicts the number of assets that were proposed for assignment by the test subjects that were unavailable.**

Based on the manual updates allowed by the interface the NPS decision was able to discern which assets were available for assignment. Assuming the information within the TACC was accurate the NPS decision aid proposed assets that were available for assignment 100% (34/34) of the time, the decision maker employing manual methods did so 94% (16/17) of the time.

Based on the scope of this evaluation the decision aid successfully answered COI 2, Asset Availability.

## D. COI 3. TARGET ASSET PAIRING. DO THE DECISION AIDS PROPERLY RECOGNIZE THE ASSETS THAT ARE AVAILABLE FOR A PARTICULAR TARGET?

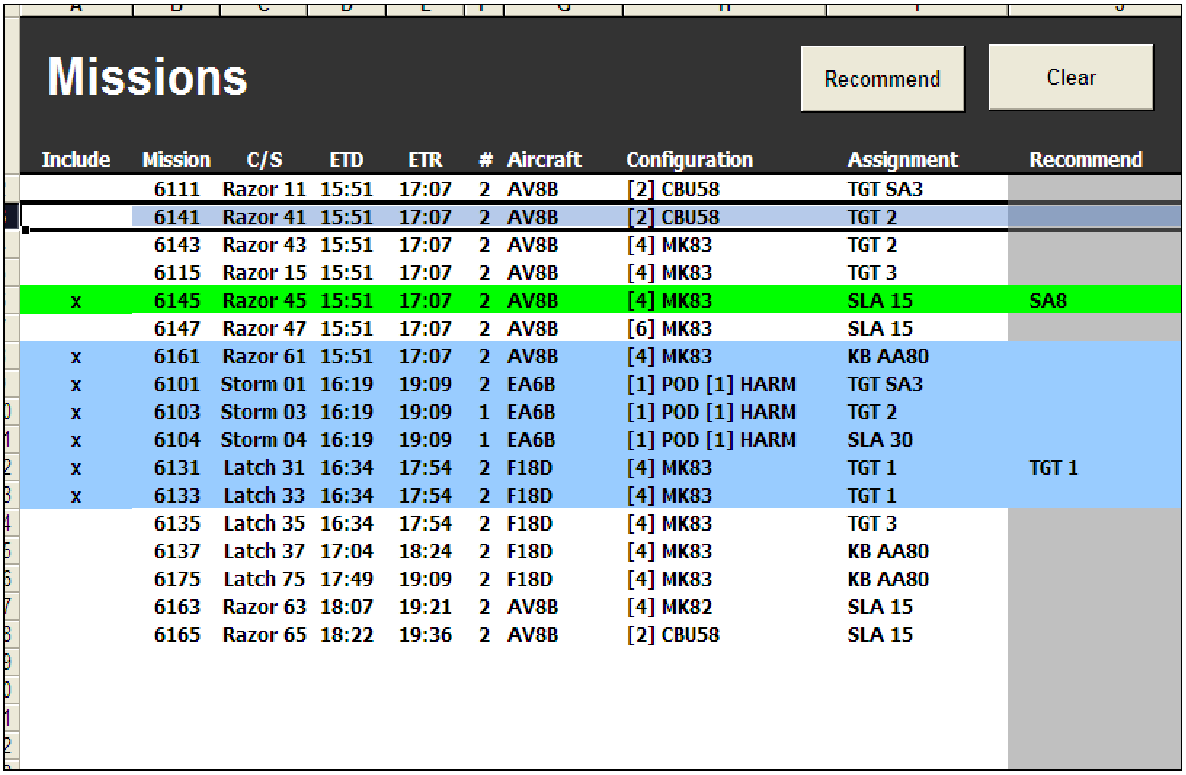
This COI addressed the ability of the assets proposed for assignment by the decision aid to destroy the target. In each event a determination was made as to whether or not the required probability of destruction for each target was achieved. The desired probability of destruction was provided by the MAWTS-1 Instructors. Any asset that was assigned that could not achieve the destruction criteria was considered a bad assignment. The scoring of this issue was done qualitatively by the MAWTS-1 Instructors. The results are depicted in Table 4 below.

| COI #3 Target Asset Planning | | | | | |
|---|---|---|---|---|---|
| | TST | Number of Selected for assignment to primary target that meet destruction criteria | | | |
| | | NPS | | DM | |
| | | # properly selected | Total Assign | # properly selected | Total Assign |
| MISTEX 1 | **1** | 3 | 3 | 0 | 0 |
| | **2** | 1 | 1 | 1 | 1 |
| | **3** | 1 | 1 | 1 | 1 |
| | **4** | 1 | 1 | 0 | 0 |
| | **5** | 1 | 1 | 0 | 2 |
| | **6** | 1 | 1 | 2 | 2 |
| MISTEX 2 | **1** | 3 | 3 | 1 | 1 |
| | **2** | 1 | 1 | 1 | 1 |
| | **3** | 2 | 2 | 2 | 2 |
| | **4** | 1 | 1 | 1 | 1 |
| | **5** | 1 | 1 | 1 | 1 |
| Finex 1 | **1** | 1 | 1 | 1 | 0 |
| | **2** | 2 | 2 | 0 | 1 |
| | **3** | 1 | 1 | 0 | 0 |
| Finex 2 | **1** | 1 | 1 | 0 | 0 |
| | **2** | 2 | 2 | 0 | 1 |
| | **3** | 2 | 2 | 0 | 0 |
| | **4** | 2 | 2 | 0 | 0 |
| Finex 3 | **1** | 1 | 1 | 0 | 0 |
| | **2** | 1 | 1 | 1 | 1 |
| | **3** | 3 | 3 | 0 | 0 |
| | **4** | 1 | 1 | 1 | 1 |
| | 5 | 1 | 1 | 1 | 1 |

**Table 4 COI 3, Results.**

In resolving this COI, a determination of whether or not the decision aid met the established criteria was simplified because the probability of successfully destroying the target is provided as part of the output seen in Figure 9, below.

This figure provides an example of the results achieved during the evaluation of TST 5, during MISTEX 1.



# Missions

Recommend | Clear

| Include | Mission | C/S | ETD | ETR | # | Aircraft | Configuration | Assignment | Recommend |
|---|---|---|---|---|---|---|---|---|---|
| | 6111 | Razor 11 | 15:51 | 17:07 | 2 | AV8B | [2] CBU58 | TGT SA3 | |
| | 6141 | Razor 41 | 15:51 | 17:07 | 2 | AV8B | [2] CBU58 | TGT 2 | |
| | 6143 | Razor 43 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | TGT 2 | |
| | 6115 | Razor 15 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | TGT 3 | |
| x | 6145 | Razor 45 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | SLA 15 | SA8 |
| | 6147 | Razor 47 | 15:51 | 17:07 | 2 | AV8B | [6] MK83 | SLA 15 | |
| x | 6161 | Razor 61 | 15:51 | 17:07 | 2 | AV8B | [4] MK83 | KB AA80 | |
| x | 6101 | Storm 01 | 16:19 | 19:09 | 2 | EA6B | [1] POD [1] HARM | TGT SA3 | |
| x | 6103 | Storm 03 | 16:19 | 19:09 | 1 | EA6B | [1] POD [1] HARM | TGT 2 | |
| x | 6104 | Storm 04 | 16:19 | 19:09 | 1 | EA6B | [1] POD [1] HARM | SLA 30 | |
| x | 6131 | Latch 31 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 1 | TGT 1 |
| x | 6133 | Latch 33 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 1 | |
| | 6135 | Latch 35 | 16:34 | 17:54 | 2 | F18D | [4] MK83 | TGT 3 | |
| | 6137 | Latch 37 | 17:04 | 18:24 | 2 | F18D | [4] MK83 | KB AA80 | |
| | 6175 | Latch 75 | 17:49 | 19:09 | 2 | F18D | [4] MK83 | KB AA80 | |
| | 6163 | Razor 63 | 18:07 | 19:21 | 2 | AV8B | [4] MK82 | SLA 15 | |
| | 6165 | Razor 65 | 18:22 | 19:36 | 2 | AV8B | [2] CBU58 | SLA 15 | |

**Figure 9 TST 5, MISTEX 1 result shows the recommended assignment, in the far right corner, of a section of AV8B Harriers to the target (SA-8).**

The proposed assignment by the decision aid of an AV-8B to strike the SA-8 represents a solution that achieves a probability of success of 94%. This is depicted in Figure 10, a screen shot of the interface for the decision aid.

**Targets**

| Include | Target | Priority | Type | Threat | Probability of Success | Probability Achieved | Probability of Attrition |
|---|---|---|---|---|---|---|---|
| | TGT SA3 | 3 | SA3 | SA3 | 75% | | |
| x | TGT 1 | 4 | Logistics Site | | 75% | 93% | 0% |
| | TGT 2 | 5 | Logistics Site | | 75% | | |
| | TGT 3 | 6 | Assembly Area | | 75% | | |
| | ZSU | 2 | ZSU | ZSU | 75% | | |
| x | SA8 | 2 | SA8 | SA8 | 75% | 94% | 0% |
| | TEL | 2 | TEL | | 75% | | |
| | SS21 | 1 | SS21 | SA6 | 75% | | |

**Figure 10. Target Pairing Results. The decision aid determined that by assigning a AV-8B Harrier to SA-8 a probability of success of 94% would be achieved. The required probability of success was only 75%.**

This same target addressed by the decision maker with no automated support was resolved by assigning an EA-6B Prowler and a FA-18D with an ordnance configuration consisting of LAU-61. In this case, this represents an inadequate solution as determined by the MAWTS-1 instructors. The reason for the determination, LAU-61s are rockets primarily used for marking targets, and are too inaccurate for a high probability of success to be achieved.

The test results indicated that the decision aid proposed a solution that met the required probability of destruction 100% (34/34) of the time. It should be noted that the decision aid was operated on an unclassified system so known probabilities of kill used in these calculations were also unclassified. Additionally, the decision aid did not take into account the implications of weather on ordnance selection, but this was not a factor in the evaluation.

The decision maker's proposed assignment was also evaluated qualitatively. The MAWTS-1 instructors determined that the accuracy of each

assignment, and as a result, the decision maker achieved the desired probability of success 82% (14/17) of the time.

Based on the scope of this evaluation the NPS Decision Aid met the COI requirements. It is recommended that in further testing classified values for probability of kill be used while employing the decision aid.

## E. COI 4. RISK ASSESSMENT. DO THE DECISION AIDS ACCURATELY ASSESS THE RISK OF PROPOSED ASSIGNMENTS?

This addresses whether or not the decision aid properly computed the level of risk to aircraft given the presence of Surface-to-Air Threats. Additionally, based on a determination of risk, an assessment of whether or not SEAD was appropriately recommended was also conducted.

Table 5, provided below, presents the results pertaining to this COI.

| COI #4 Risk Assessment | | | | | |
|---|---|---|---|---|---|
| | TST/Threat Type | Probability of Attrition | | | |
| | | NPS | | DM | |
| | | % | Total Assign | % | Total Assign |
| MISTEX 1 | 1 | 0 | 3 | 0 | 0 |
| MISTEX 1 | 2 | 0 | 1 | 0 | 1 |
| MISTEX 1 | 3 | 0 | 1 | 0 | 1 |
| MISTEX 1 | 4 | 0 | 1 | 0 | 0 |
| MISTEX 1 | 5/SA8 | 0 | 1 | Y | 2 |
| MISTEX 1 | 6/SA8 | 0 | 1 | Y | 2 |
| MISTEX 2 | 7 | 0 | 3 | 0 | 1 |
| MISTEX 2 | 8 | 0 | 1 | 0 | 1 |
| MISTEX 2 | 9/SA6 | 0.5 | 2 | Y | 2 |
| MISTEX 2 | 10 | 0 | 1 | 0 | 1 |
| MISTEX 2 | 11 | 0 | 1 | 0 | 1 |
| Finex 1 | 12 | 0 | 1 | 0 | 0 |
| Finex 1 | 13/SA6 | 0.6 | 2 | Y | 1 |
| Finex 1 | 14 | 0 | 1 | 0 | 0 |
| Finex 2 | 15/SA8 | 0 | 1 | 0 | 0 |
| Finex 2 | 16/SA6 | 0.6 | 2 | Y | 0.2 |
| Finex 2 | 17/SA6 | 0.6 | 2 | 0 | 0 |
| Finex 2 | 18/SA6 | 0.6 | 2 | 0 | 0 |
| Finex 3 | 19 | 0 | 1 | Y | 0 |
| Finex 3 | 20 | 0 | 1 | 0 | 1 |
| Finex 3 | 21/SA6 | 0.6 | 3 | 0 | 0 |
| Finex 3 | 22 | 0 | 1 | 0 | 1 |
| Finex 3 | 23/SA6 | 0 | 1 | Y | 1 |

**Table 5. Risk Assessment. The table identifies for each assignment the probability or risk of losing an aircraft as a result of a Surface-To-Air Threat.**

In each case the same assessment was similar for both the decision aid and the unaided decision maker. The probabilities of an aircraft being destroyed (attrition) are based on unclassified data. In Table 6 below, a determination for each target for the requirement of SEAD is made. Using this determination a comparison is conducted to determine the rate at which SEAD was properly recommended. The data reveals that the decision aid recommended SEAD

correctly 80% (4/5) of the time. By comparison the decision maker also recommended SEAD 80% (4/5) of time.

| | SEAD Requirement | | |
|---|---|---|---|
| | SEAD Required | SEAD Recommended | |
| **TST** | **(MAWTS-1)** | **NPS** | **DM** |
| **1** | N | N | N |
| **2** | N | N | N |
| **3** | N | N | N |
| **4** | N | N | N |
| **5** | N | N | Y |
| **6** | N | N | Y |
| **7** | | N | - |
| **8** | - | N | N |
| **9** | Y | Y | Y |
| **10** | N | N | - |
| **11** | N | N | Y |
| **12** | | N | - |
| **13** | - | N | N |
| **14** | N | N | N |
| **25** | N | N | - |
| **16** | Y | Y | Y |
| **17** | Y | Y | - |
| **18** | Y | Y | N |
| **19** | N | N | Y |
| **20** | N | N | N |
| **21** | N | N | N |
| **22** | N | N | N |
| **23** | Y | N | Y |

**Table 6, SEAD Recommendation. The table indicates whether or not the test subjects recommended the assignment of SEAD when it was determined necessary by the MAWTS-1 Instructors.**

Of note is TST 23, in this case the decision maker assessed the risk of losing an aircraft to be 60%, based on the capabilities of an SA-6. Although SEAD was recommended in this case, none was available. The decision maker chose to assign an aircraft and accept the risk. By comparison, the decision aid did not recommend SEAD. Instead the proposed solution was to assign an available section of AH-1W helicopters. Due to their ability to use terrain to mask themselves from the threat, the risk of attrition was limited. What is not assumed

by the decision aid is that the threat, an SA-6, is customarily accompanied by a low altitude anti-aircraft artillery (AAA) threat, resulting in a poor assignment.

Based on the scope of this evaluation it can be concluded that the decision aid accurately assessed risk and recommended SEAD when required. It is recommended that the decision aid should be modified to incorporate a realistic employment of enemy threat systems when employing helicopter assets.

## F. COI 5. PERSISTENCE. DO THE DECISION AIDS MINIMIZE THE NUMBER OF CHANGES TO THE ATO TO ACHIEVE MISSION ACCOMPLISHMENT?

The test determined if the decision aid minimized the number of changes for each TST event required to obtain the desired effects on the targets being attacked during the vulnerability window. The impact of the decision on the effectiveness of other missions was not evaluated, therefore averages could be misleading. To make this determination the decision maker would have to employ each recommendation made by the decision aid. This did not fall within the scope of the evaluation. The following results, displayed in Table 7, provide a basis for determining the average number of changes for each TST event.

| | COI #5 Persistence | | |
|---|---|---|---|
| | **TST** | **Number of Changes to the ATO Required by proposed solution** | |
| | | **NPS** | **DM** |
| | | **#** | **#** |
| MISTEX 1 | **1** | 1 | 0* |
| | **2** | 1 | 1 |
| | **3** | 1 | 1 |
| | **4** | 1 | 0* |
| | **5** | 1 | 2 |
| | **6** | 1 | 2 |
| MISTEX 2 | **7** | 3 | 1 |
| | **8** | 1 | 1 |
| | **9** | 2 | 2 |
| | **10** | 1 | 1 |
| | **11** | 1 | 1 |
| Finex 1 | **12** | 1 | 0* |
| | **13** | 2 | 1 |
| | **14** | 1 | 0 |
| Finex 2 | **15** | 1 | 0* |
| | **16** | 2 | 1 |
| | **17** | 2 | 1 |
| | **18** | 1 | 0* |
| Finex 3 | **19** | 1 | 0* |
| | **20** | 1 | 1 |
| | **21** | 3 | 0* |
| | **22** | 1 | 1 |
| | 23 | 1 | 1 |

**Table 7. COI 5, Persistence. The table provides the number of required changes to be made by the decision maker for each TST event in order to execute the proposed solution.**

From the table we can conclude that on average the decision aid solution required 1.7 (31/23) changes with a maximum of three. The decision maker solution on average required 0.75 changes (17/23) with a maximum of two. In the event that the decision maker did not require a change as indicated by an (*) in Table 6, one of two possibilities occurred; the decision maker chose to not strike the TST, or elected to address the target using indirect fires. Indirect fires

are not an option for the decision aid. Furthermore on average for every TST there were 4.7 (110/23) missions available for assignment. The number of available missions ranged from one to eight.

Based on these results the conclusion is that the decision aid does appear to minimize the number of changes per event, but requires further testing to be conclusive.

## G. COI 6. DECISION SPEED. DO THE DECISION AIDS PROVIDE A PROPOSED SOLUTION FAST ENOUGH TO BE EFFECTIVE WHEN COMPARED TO CURRENT METHODS?

This COI addresses the ability of the decision aid to propose a solution in enough time to strike a target within a specified vulnerability window. During this evaluation, no vulnerability window was specified for each target. A vulnerability window can vary depending on the target. The default vulnerability window for this exercise was determined to be 20 minutes. This window was chosen because it provided a more stringent case to conduct the evaluation. As a result the decision aid was held to a tighter requirement than the decision maker. Table 8 provides the decision speed for each event. The scoring of time begins with the receipt of a target report, it concludes with the proposal of a decision by the decision aid and the decision maker.

| | COI #6 Timeliness | | | |
|---|---|---|---|---|
| | TST | Decision Time (sec) | | |
| | | NPS | | DM |
| | | Input Time | Solution Time | Decision Time |
| MISTEX 1 | 1 | 60 | 2 | - |
| | 2 | 60 | 2 | 180 |
| | 3 | 120 | 2 | 60* |
| | 4 | 60 | 2 | 360 |
| | 5 | 120 | 2 | 180 |
| | 6 | 60 | 2 | 180 |
| MISTEX 2 | 1 | 45 | 2 | 240 |
| | 2 | 30 | 2 | 60 |
| | 3 | 120 | 2 | 2280 |
| | 4 | 45 | 2 | 720 |
| | 5 | 45 | 2 | 360 |
| Finex 1 | 1 | 120 | 8 | 180 |
| | 2 | 60 | 2 | 480 |
| | 3 | 50 | 2 | 180 |
| Finex 2 | 1 | 30 | 2 | 180 |
| | 2 | 30 | 2 | 60 |
| | 3 | 60 | 2 | 900 |
| | 4 | 30 | 2 | 1200 |
| Finex 3 | 1 | 120 | 2 | 720 |
| | 2 | 120 | 2 | 900 |
| | 3 | 50 | 2 | 540 |
| | 4 | 120 | 2 | 1200 |
| | 5 | 60 | 2 | 60 |

**Table 8. COI 6. Decision Speed. The table provides the time in seconds for the test subjects to recommend a solution to the target.**

Based on the results depicted in the table, the decision aid on average provided a solution in 1.7 minutes (1167sec/23), with a range of one to two minutes. By comparison the decision maker provided a solution, on average, in 8.4 minutes (11160 sec/22), with a range of one minute to 38 minutes. By observation there appears to be a significant military difference.

The conclusion is that the decision aid on average does provide a recommendation within the time required (2-3 minutes) to make an effective decision. Therefore, the COI has been satisfactorily met.

## H. COI 7. OPTIONS. DO THE DECISION AIDS PROVIDE THE DECISION MAKER WITH MULTIPLE ALTERNATIVE SOLUTIONS FOR MISSION RE-TASKING WHEN AVAILABLE?

Every decision maker will weight the effect of a proposed solution differently. This can be attributed to the varying background and experience of each decision maker. As a result the number of options available may improve the quality of the decision. This COI addresses the ability of the decision aid to provide the decision maker with different courses of action.

The test results showed the decision aid was only able to provide the decision maker with one course of action. As a result, for each TST event, the COI was not satisfactorily met. This can be attributed to the design of the decision aid. It is recommended that the decision aid be modified to provide multiple solutions.

## I. COI 8. TACTICALLY ACCURATE. DOES THE DECISION AIDS' OUTPUT PROVIDE TACTICALLY ACCEPTABLE ASSIGNMENTS?

The focus of this COI was to evaluate if the results provided by the decision aid represent assignments that were tactically accurate. The assessment of this COI was qualitative in nature. At the conclusion of each evolution, the MAWTS-1 instructor reviewed the proposed assignment for each TST, and a decision was made. In each of the twenty-three events the instructor concluded that assignments proposed by the decision aid represented tactically acceptable solutions. The following example shows an instance where the decision aid solution was considered accurate, while by comparison, the decision maker's solution was not.

During FINEX 3 at 2104, a FROG-7 surface-to surface missile system was located and the TACC was informed. Figure 11, depicts the assets available at the time the target emerged.

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DOWN | M | 6142 | LATCH 21 | - | CAS | 4/16 19:00 | 4/16 20:00 | 2 | FA18 | [6] MK83 | KNYL | R2301 |
| N/A | M | 6144 | RAZOR 11 | - | CAS | 4/16 19:00 | 4/16 19:50 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| DOWN | X | 1010 | NITEMARE | - | CAS | 4/16 19:30 | 4/16 20:15 | 2 | AV8B | [6] MK82 | - | NTAC-STAC |
| DOWN | M | 6151 | RAZOR 21 | - | CAS | 4/16 19:30 | 4/16 20:20 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| x | M | 6155 | LATCH 31 | - | TAC | 4/16 19:30 | 4/16 22:00 | 2 | FA18 | [4] LAU68 | KNYL | R2301 |
| x | M | 6161 | LATCH 41 | - | CAS | 4/16 19:55 | 4/16 21:25 | 2 | FA18 | [6] MK83 | KNYL | R2301 |
| DOWN | M | 6153 | STORM 11 | - | ES | 4/16 20:00 | 4/17 00:30 | 1 | EA6B | [1] POD [1] HARM | KNYL | R2301 |
| N/A | M | 6157 | LATCH 51 | - | CAS | 4/16 20:10 | 4/16 21:50 | 2 | FA18 | [6] MK83 | KNYL | R2301 |
| N/A | X | 1012 | BAT | - | CAS | 4/16 20:15 | 4/16 21:30 | 2 | FA18 | [6] MK83 | - | NTAC-STAC |
| N/A | M | 5027 | VENOM 31 | | OAS | 4/16 20:15 | 4/17 02:00 | 4 | AH1W | [3] A114 [3] A71 | KNYL | R2301 |
| x | M | 6163 | RAZOR 41 | - | CAS | 4/16 20:30 | 4/16 21:20 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| DOWN | M | 6165 | RAZOR 43 | | CAS | 4/16 20:40 | 4/16 21:30 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| DOWN | M | C5045 | VENOM 51 | - | CAS | 4/16 20:45 | 4/17 02:00 | 2 | AH1W | [3] A114 [3] A71 | KNYL | AJO |
| x | X | 1014 | KNITE | - | CAS | 4/16 21:30 | 4/16 22:15 | 2 | FA18 | [6] MK83 | - | NTAC-STAC |
| x | M | 6167 | RAZOR 51 | - | CAS | 4/16 21:30 | 4/16 22:20 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| N/A | M | C5043 | DEUCE 21 | - | CAS | 4/16 21:30 | 4/17 00:30 | 1 | UH1N | [2] LAU61 | KNYL | AJO |
| | M | 6171 | RAZOR 61 | - | CAS | 4/16 22:20 | 4/16 23:10 | 2 | AV8B | [6] MK82 | KNYL | R2301 |
| | X | 1016 | CAT | - | CAS | 4/16 22:45 | 4/16 23:30 | 2 | AV8B | [6] MK82 | - | NTAC-STAC |

**Figure 11. FINEX 3 ATO. The assets outlined indicate the available assets at the time of the emerging TST. From these available assets a solution can be proposed to strike the target.**

In the vicinity of the target, an SA-8 was known to exist. Based on these inputs the decision aid determined the best asset for assignment to be mission 6163, a section of AV-8B Harriers, that had launched at 2145. The mission was previously assigned in general support of CAS missions and was available for assignment to a higher priority mission. By comparison the decision maker chose to re-assign nothing, citing the threat as the factor. During post-evolution analysis the MAWTS-1 instructor determined that the SA-8 did not pose a viable threat to the fixed wing aircraft operating at altitude. For this example it was concluded that the decision aid proposed the correct course of action, while the decision maker did not.

Based on the scope of the evaluation it is determined that the decision aid meets the tactical accuracy requirements of this COI satisfactorily.

## J. COI 9. INTEROPERABILITY. DO THE DECISION AIDS OPERATE CORRECTLY WITH THE CURRENT C4I ARCHITECTURE?

This COI addresses the ability of the decision aid to interoperate satisfactorily in the tactical environment with existing systems. During the course of the evaluation, five ATO were developed and transmitted to the exercise force. In all cases the decision aid was able to accept the ATO and perform its necessary tasks. The ATO parser developed to perform this function was

reviewed by the unit and has since been approved for incorporation into everyday operations. Based on these results the requirements of the COI have been met. However, it is recommended that for future testing that the decision aid be adapted to accept real time updates over the tactical data network. This would enhance the effectiveness of the decision aid to determine available resources at a given moment. This process is currently conducted manually and subject to error.

## K. COI 10. SOFTWARE RELIABILITY. CAN THE DECISION AIDS OPERATE CONTINUOUSLY WITHOUT INTERRUPTION OR FAILURE FOR A PROLONGED PERIOD OF TIME?

This COI addressed the decision aids ability to function continuously without interruption over the course of each evolution. The length of each evolution ranged from two to seven hours. During each evolution the decision aid operated continuously without interruption. It can be concluded, based on the limited scope of this evaluation that the decision aid appears to meet this COI. For a final determination it is recommended that the decision aid be employed during exercises of much longer duration.

## L. CONCLUSION

During the evaluation ten of the eleven planned COI’s were evaluated. The overall results are depicted in Table 9.

| COI | NPS DECISION AID RESULT | | |
|---|---|---|---|
| | Adequate | Inadequate | Unresolved |
| COI 1 | X | | |
| COI 2 | X | | |
| COI 3 | X | | |
| COI 4 | X | | |
| COI 5 | X | | |
| COI 6 | X | | |
| COI 7 | | X | |
| COI 8 | X | | |
| COI 9 | X | | |
| COI 10 | X | | |
| COI 11 | | | X |

**Table 9 COI Evaluation Results.**

Within the scope of MISTEX/FINEX evaluation all critical issues addressed were satisfactorily met except for COI 7, the number of options provided by the decision aid. COI 11, Human Factors, was not able to be adequately addressed by this evaluation.

## M. TEST LIMITATIONS

The evaluation was limited by the following factors. The scenario used in the evaluation did not allow for targets in an urban environment. The environment did not incorporate adverse weather effects, which limited the evaluation of asset-target pairing. Specifically, low altitude threat systems could be countered with high altitude tactics, therefore, eliminating the requirement for SEAD in most cases. Finally, the duration of the exercise limited the assessment of software reliability. As a result it is recommended that further testing include operations of at least 24 hours in duration.

Chapter VI, provides a summary of the conclusions and recommendations generated by the MISTEX/FINEX evaluations.

# VI. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS AND IMPACT

The emergence of Time Sensitive Targets (TST) poses an imminent threat to friendly forces and the successful completion of the friendly commanders mission. Failure to decide and act within a short period of time, specified by a target's vulnerability window, results in loss of life or the disruption of a vital area.

The tactical decision aid developed in this thesis provides the decision maker with a fast, accurate, and appropriate aviation response to the emergence of a TST. The decision aid employs optimization techniques that incorporate all available resource information provided by the Air Tasking Order (ATO), including: the number and type of aircraft, ordnance load, time window, and the aircrafts' previously assigned task. Coupled with commander's guidance in the form of a prioritized list of targets, and assessment of the threat, the decision aid determined which asset to assign to each target within the vulnerability window.

The tactical decision aid was successfully demonstrated in the live tactical environment at Marine Aviation Weapons and Tactics Squadron One, Yuma, Arizona. The results of the Critical Operational Issues (COI) addressed by the tactical decision aid are summarized below:

**COI 1. Target Selection.** The decision aids properly conduct target prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets.
**COI 2. Asset Availability.** The decision aids properly recognize the assets that are available for a particular target.
**COI 3. Target Asset Pairing.** The decision aids properly recommend assets that have the ability to destroy the target.
**COI 4. Mission Risk Assessment.** The decision aids accurately assess the risk of its proposed assignments.
**COI 5. Persistence.** The decision aids minimize the number of changes to the ATO to achieve mission accomplishment.
**COI 6. Timeliness.** The decision aids provide a proposed solution fast enough to be effective when compared to current methods.
**COI 7. Options.** The decision aids did not provide the decision maker with multiple alternative solutions for mission re-tasking when available.
**COI 8. Tactical Accuracy.** The decision aids output provide tactically

acceptable assignments.

**COI 9. Interoperability.** The decision aids operate correctly with the current C4I architecture.

**COI 10. Software Reliability.** The decision aids operate continuously without interruption or failure for a prolonged period of time.

The conclusion is that the decision aid can significantly improve combat effectiveness against the emergence of a TST.

## B. RECOMMENDATIONS

Based on the results of the test and evaluation the following recommendations are provided to enhance future performance of the decision aid in a tactical environment.

### 1. Classified Values

The decision aid during the test and evaluation functioned on an unclassified level. Therefore, it is recommended that future employment of the decision aid employ the following classified values:

a. Ordnance single point probability of kill.

b. Aircraft Survival Probabilities.

c. EA-6B Prowler Suppression Probabilities.

The incorporation of more accurate, classified values, increases the accuracy of the overall selection of the asset selected to strike a particular target.

### 2. Rotary Wing Assets

The decision aid was expanded during the test and evaluation to incorporate the inclusion of rotary wing aircraft into strikes packages. When considering the employment of rotary wing aircraft, an integrated air defense system has to be assumed. Survival Probabilities for rotary wing aircraft against medium altitude threats, such as the SA-6, need to assume the presence of low altitude anti-aircraft weapon systems, even though they are not normally specified. This is a valid tactical assumption that was not considered in the development of the decision aid and is required when allowing rotary assets to be considered in a feasible solution set.

### 3. Interoperability

The decision aid is currently able to receive and parse an ATO from the current system of record, the Theater Battle Management Core System (TBMCS). However, it is recommended that the decision aid be further enhanced to receive near real time updates in regards the aircraft status.

### 4. Alternative Solution Proposal

The decision aid currently proposes only one solution option per TST event. It is recommended that the decision aid provide at least three to meet the needs of the tactical commander, as recommended by the instructors at Marine Aviation Weapons and Tactics Squadron One.

### 5. Software Reliability

The duration of each exercise for the test and evaluation varied from three to eight hours in length. Normal tactical operations run at least 24 hours in length. Although no software interruptions were encountered during the test and evaluation, it is recommended that more testing be done to support the conclusion of reliability.

## C. FURTHER RESEARCH

The following sections provide recommendations for additional research stemming from this thesis.

### 1. ATO Development

The decision aid has proven effective in re-optimizing the current ATO due to an immediate change in the tactical situation. Testing revealed that employing an optimization tool during ATO development, as well as, execution could have a similar impact in solution time and accuracy of aircraft assignments.

### 2. Weather Effects

To consideration of weather effects on weapon selection is not a consideration of the current decision aid. The incorporation of this type of effect will further improve the accuracy of each asset assignment.

### 3. Collateral Damage Estimation

A TST can emerge anywhere on the battlefield. However, significant concern is given to the TST that emerges in an urban environment where the cost of attacking a TST can manifest itself in civilian casualties. The ability to minimize the effects of asset selection on factors outside of the target provides a current and tactically relevant subject for further research.

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# APPENDIX A - TACTICAL DEVELOPMENT AND EVALUATION (TAC D&E) TEST PLAN

**Evaluation of Decision Aids for Dynamic Re-Targeting of Aviation Assets**

March 2004

by

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Estimated Completion Date: 1 MAY 2004

**Tactical Development and Evaluation (TAC D&E) Test Plan**

**Tactical Demonstration (TACDEMO) of Decision Aids for Dynamic Retasking of Aviation Assets**

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## 1.0 INTRODUCTION

### 1.1 Purpose

This tactical evaluation will assess and compare alternative methods in determining real time re-assignment of aircraft to time sensitive or high priority targets through either automated or manual means. These will include:

1. Current manual assignment procedures based on military judgment and experience taught in the Weapons and Tactics Instructors (WTI) Course.

2. Currently Available Software Packages employed by operating forces.

3. The Rapid Asset Pairing Tool (RAPT), a genetic-algorithm based optimization tool under development by SPAWAR.

4. An integer-programming based optimization tool developed by Major Davi Castro and Professor Richard E. Rosenthal of the Operations Research Department, Naval Postgraduate School (NPS).

### 1.2 System Description

This tactical evaluation will be accomplished within the Marine Tactical Air Command Center (TACC) present during the Weapons Tactics Instructors (WTI) Course. Assignment of aircraft to reactive targets by employing manual methods will be conducted by the students of the Weapons and Tactics Instructor's Course. These students are experienced officers in the aviation community going through instructor qualifications. These students will be aided by the employment of current command and control systems that may or mat not employ any optimization techniques. RAPT, an optimization tool designed by SPAWAR, has the capability to be integrated into the exercise command and control architecture and receive near real time updates concerning the friendly and enemy situation. These updates include but are not limited to aircraft availability, time on station, and ordnance load out. If this level of integration is unable to be accomplished, RAPT as well as a similar tool developed by NPS can and will operate independently by relying on manual inputs by the test personnel. The ultimate goal of this evaluation is to determine the tactical quality

of each systems output compared to that of an experienced operator using current methods. A reliance on manual inputs of the system will merely identify a need for further development in integration of the system.

## 2.0 Mission Need and Operational Requirement

### 2.1 Mission Need

The following mission need statement outlined in the Joint Mission Planning System (JMPS) Operational Requirements Document (ORD) has been the guiding element in developing the Rapid Asset Pairing Tool (RAPT) by SPAWAR. To achieve the Joint Vision 2020 (JV2020) operational concepts of dominant maneuver and precision engagement, future systems must be designed to streamline many areas of the targeting/decision cycle, including receipt of initial tasking/Commander's Intent, gathering/disseminating intelligence, joint/unit-level detailed planning, dynamic mid-mission re-tasking, and mission effectiveness assessment. Factors driving the need for streamlined and shorter mission planning cycle times include mobility of targets, the complex/dynamic environment of large numbers of joint assets, and greater dependency of modern aircraft/precision weapons on large quantities of intelligence data. In this highly dynamic battlespace, successful execution will depend on a planning system that provides seamless and efficient access to all required data sources, including those maintained on systems operating at differing classification levels, and manipulates the data to provide information, data products and options to planners in user friendly formats. JV 2020 envisions expanding roles for multinational and interagency partners, which will require collaborative planning capabilities, technological compatibility/ interoperability, and mechanisms for efficient information sharing.

The focus in the development of RAPT has been on three key elements identified within the mission need statement. They are: "to streamline many areas of the targeting/decision cycle, dynamic mid-mission re-tasking, and mission effectiveness assessment." [JMPS ORD, 2002]

### 2.2 Operational Requirement

The following is a list of user defined operational requirements to be used in the evaluation of the systems developed by SPAWAR and the Naval Postgraduate School.

System software will be able to be mounted on current deployable computing hardware.
System will be able to operate continually without interruption for 72 hours.
System will be able to determine most effective asset to target pairing to be used given an aircraft type, ordnance load, and associated threat type.
System will be able determine overall risk to assigned aircraft given a specific threat.
System will be able to receive an ATO transmitted by TBMCS.
Aircraft assignment will appear as a system output in a timely manner.
System will be able to measure current impact of decision to the Air Tasking Order.
System will be intuitive and require minimal training.

## 3.0 SCOPE OF THE EVALUATION

### 3.1 Critical Technical Parameters

The following is a list of user defined Critical Technical Parameters to be used in the evaluation of the systems developed by SPAWAR and the Naval Postgraduate School.

- At a minimum the system will be able to receive data from TBMCS and the
- Joint Mission Planning System (JMPS).
- Proposed assignment will have a probability of destruction $\geq$ prescribed destruction criteria for the given target.
- System will determine either a probability of survival or expected attrition rate of assets assigned against the given target.
- System output will provide at a minimum, 3 proposed target assignments, assets permitting.
- Proposed aircraft/target assignments will be completed within one minute.
- System can parse an ATO with a minimum 100 sorties and maximum 5000.
- System will display at minimum:
  - Probability of Destruction
  - Risk Assessment or Expected Value of Attrition
- Persistence measurement will convey number of changes or percentage impact to the ATO
- Current Mission Number
- Ordnance Load-out
- Previously Assigned Target and its priority
- New Target, its Priority, and Associated threat

### 3.2 Critical Operational Issues

**COI 1.0** - **Target Selection**: Does the system properly assess prioritization of targets to ensure mission accomplishment of higher priority targets before lower priority targets? Targets are prioritized numerically beginning with one, the highest priority target. Given a situation where all assets are currently assigned the potential for a target not being struck exists. Each decision tool must be able to accurately assign assets so that the higher priority targets are paired with assets.

**MOE 1.1** - Accurate target selection

**MOP 1.1.1** - Percent properly selected

**DR 1**.1**.1.1** – Total Missions assigned.

**DR 1.1.1.2** - Number of Missions not assigned with a higher priority by RAPT or NPS tool.

**DR 1**.1**.1.3 –** Number of Missions not assigned by DM without the aid of an automated tool

**COI 2.0** - **Asset Availability**: Does the system properly determine the assets that are available for a particular target in its analysis? Available assets are those that have not been cancelled on the ATO for mechanical failures or those that have been sent on to original target.

**MOE 2.1** - Asset consideration accuracy

**MOP 2.1.1** - Percent available considered. Determined by the number of assignments made that consisted of available missions. This does not include missions that have already proceeded to original target, or that have been canceled due to maintenance.

**DR 2.1.1.1** - Actual number of aircraft available and capable

**DR 2.1.1.2** - Number assigned that were considered available and capable by the NPS or RAPT tool.

**DR 2**.**1.1.3** – Number assigned that were considered available and capable by the DM without the aid of an automated tool.

**COI 3.0** - **Target Asset Pairing**: Does the system ensure aircraft are properly reassigned to targets they can destroy the target? Each mission's ordnance load against a given target can be computed by the decision aids to determine a level of destruction. We wish to determine if this destruction level is equal to greater than the destruction criteria required for each target assigned an asset by the decision aid. Assets assigned that meet the desired destruction criteria will be considered a correct assignment.

**MOE 3.1** – Allocation Plan

**MOP 3.1.1** – Percent Correct Assignments

**DR 3.1.1.1-** Number of assignments made by NPS or Rapt tool that could not destroy targets

**DR 3.1.1.1-** Number of assignments made by DM without the aid of an automated tool that could not destroy targets

**DR 3.1.1.2**- Total Number of assignments

**COI 4.0** - **Mission Risk Assessment**: Does the system accurately assess risk in its reassignments? Given a threat associated with a given target each decision aid is expected to compute a level of risk to the assets proposed for assignment.

**MOE 4.1** – Rate at which is accurately assessed

**MOP 4.1.1** - Percent properly assessed. Assessment to be done by qualified instructors on the MAWTS-1 Staff.

**DR 4.1.1.1** - Computed risk assessment for each target/aircraft pair

**DR 4.1.1.2** – Risk Assessment by DM.

**MOE 4.2-** Proper SEAD recommendation based on Risk assessment

**MOP 4.2.1-** Percent SEAD assignments made when required

**DR 4.2.1-** Actual SEAD assignments made when required by RAPT or NPS tool.

**DR 4.2.1-** Actual SEAD assignments made when required by DM.

**DR 4.2.2-** Number of SEAD assignments requiring SEAD support.

**COI 5.0** - **Persistence in ATO**: Does the system minimize the number of changes to the ATO to achieve mission accomplishment? Each decision aid is expected to select an asset for assignment that is affords the least impact to existing assignments.

**MOE 5.1** - ATO Persistence.

**MOP 5.1.1** – Number of changes to the current ATO

**DR 5.1.1.1** - Number changes required for re-tasking using RAPT or NPS tool for each new target input.

**DR 5.1.1.2** - Number changes required for re-tasking by DM without the aid of an automated tool for each new target input.

**COI 6.0** - **Timeliness**: Is the system fast enough to be effective compared to current methods?

**MOE 6.1** - Decision Speed

**MOP 6.1.1** - Average time to output recommendation to the DM

**DR 6.1.1.1** - Time from receipt of target, to solution recommended to DM with the NPS or RAPT tools

**DR 6.1.1.2** - Time from receipt of target, to solution recommended to DM without the decision aid.

**COI 7.0** - **Options**: Does the system provide the decision maker with multiple alternative solutions for mission re-tasking when available?

**MOE 7.1** - Multiple alternative generation

**MOP 7.1.1** - Number of provided to available alternatives

**DR 7.1.1.1** - Number of alternatives provided by the NPS or RAPT tool

**DR 7.1.1.2** - Number of alternatives provided to DM without the aid of an automated tool.

**COI 8.0** – **Tactical Accuracy**: Does the system output provide tactically acceptable assignments to ensure the ability of assets reassigned to accomplish the mission? The output for each assignment will be assessed to determine if

the proposed assignments are reasonable. This is not assessment of optimality but a determination of whether or not the proposed solution is one of many possibilities.

**MOE 8.1** - Probability of correct output is tactically acceptable

**MOP 8.1.1** – Percent output is tactically unacceptable

**DR 8.1.1.1** – Number of acceptable assignments

**DR 8.1.1.2-** Number of assignments made

**COI 9.0** - **Interoperability**: Does the system operate correctly with the current C4I architecture?

**MOE 9.1** - Probability of properly receive the ATO

**MOP 9.1.1** - Percent of ATO received properly

**DR 9.1.1.1** - Number of ATOs received

**DR 9.1.1.2** - Number of ATOs sent

**COI 10.0 – Software Reliability:** Can the automated tools operate continuously without interruption or failure for a prolonged period of time?

**MOE 10.1 –** Reliability

**MOP 10.1.1** – Mean time before failure

**DR 10.1.1.1** – Time between each failure for the RAPT and NPS tool

**COI 11.0** - **Human Factors**: Can the typical user enter inputs and understand outputs in an efficient, intuitive manner with minimal training?

**MOE 11.1** - Display

**MOP 11.1.1** - Percent operators satisfied with the display.

**DR 11.1.1.1** – Number satisfied w/ Probability of destruction display

**DR 11.1.1.2** - Number satisfied w/ Risk Assessment display

**DR 11.1.1.3** – Number satisfied w/ Persistence measurement display

**DR 11.1.1.4** – Number satisfied w/ Current Mission Number display

**DR 11.1.1.5** – Number satisfied w/ Ordnance Capability display

**DR 11.1.1.6** - Number satisfied w/ display regarding the previously assigned target, its priority, and associated threat.

**DR 11.1.1.7**- Number satisfied w/ the display regarding the New Target and its priority and associated threat

**DR 11.1.1.8** – Total number of Operators

**Table 1. Test Objective Matrix**

| COI | Test Objectives and Sub-Objectives | Test |
|---|---|---|
| Target Selection | To determine if system properly selects targets for assignment to ensure mission accomplishment of higher priority targets before lower priority targets.<br>-Accuracy<br>-System consistency with manual methods | E-1 |
| Asset Availability | To evaluate if the system properly determines the assets that are available for a particular target.<br>-Proportion considered | E-2 |
| Target Asset Pairing | To assess if the system properly reassigns aircraft to targets they can destroy at a certain level of confidence.<br>-Proportion correctly calculated<br>-Probability of kill for assigned aircraft | E-3 |
| Mission Risk Assessment | To determine if the system avoids undue risk in its reassignments.<br>-Proportion properly assessed<br>-SEAD Assignment recommendation | E-4 |
| Persistence in ATO | To determine if the system minimizes the number of changes to the ATO to achieve mission accomplishment.<br>-Proportion properly predicted<br>-Persistence ratio | E-5 |
| Timeliness | To assess if the system is fast enough to be effective compared to current methods.<br>-Decision time | E-6 |
| Options | To determine if the system provides the decision maker with multiple alternative solutions for mission retasking, when available.<br>- Provided to available alternatives | E-7 |
| Tactical Accuracy | To determine if system recommendations for asset pairing is tactically accurate. | E-8 |
| Software Reliability | To determine if the automated tools can operate for continuously without failure.<br>-Mean time before failure | S-1 |
| Interoperability | To determine if the system operates correctly with the current C4I architecture.<br>- ATOs received correctly<br>- Updates received | S-2 |
| Human Factors | To evaluate if the typical user can enter inputs and understand outputs in an efficient, intuitive manner with minimal training.<br>-Displays<br>-Training time<br>-Interpretation errors | S-3 |

## 3.4 General Test Operations, Test Vehicles, and Scenario Overview

### 3.4.1 General Test Operations

The evaluation will be conducted during the Weapons Tactics Instructor's Course (WTI) 2-04. The course is executed by Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) located at Marine Corps Air Station (MCAS) Yuma, Arizona. The tools and methods to be evaluated will be located in the Marine Tactical Air Command Center (TACC). The TACC is the senior aviation command and control agency for the Marine Corps and is ultimately responsible for the conduct of the air war, to include real time re-tasking of aviation assets. WTI is designed to train and evaluate the Marine Corps experienced Aviators, Command and Control Officers, and Aviation Ground Support Officers in the conduct of their assigned specialties. Once training is complete the officers and enlisted personnel are sent back to their units to become the resident experts for the unit. Within the Marine Corps aviation community, WTI has been referred to as a graduate level course for tactics.

The execution of a WTI course presents a unique opportunity to evaluate not just our Marines, but the tools developed to support the conduct of their mission. The course is divided into two phases; Academic and Flight. The flight phase will provide the vehicle for this evaluation.

During the flight phase the evaluation will focus on only the final two separate flight phase evolutions. The MACCS Integrated Simulated Training Exercise (MISTEX), and the Final Exercise (FINEX) will comprise the specific test vehicles for the evaluation.

MISTEX is a static exercise consisting of the entire Marine Aviation Command and Control System in the field executing a realistic, low intensity, tactical scenario over a two-hour period. This MISTEX scenario is executed twice over a two-day period to ensure the MACCS is fully operational prior to the beginning of flight operations.

FINEX is the culminating exercise of the WTI course. It is highly intensive and demonstrates all six functions of Marine Aviation. These six functions include Control of Aircraft and Missiles, Anti-Air Warfare, Offensive Air Support, Assault Support, Air Reconnaissance, and Electronic Warfare. Functions are driven by a tactical scenario where command and control officers are exercising their delegated authority in the direction and control of aircraft. The determination of whether or not our tools can adequately support the decision makers in this type of operation will be assessed during this evolution.

### 3.4.2 Scenario Overview

The scenario, for the purposes of the evaluation consists of offensive and defensive combat operations involving ground and air forces against a heavy mechanized division in a desert environment. The enemy air capabilities consist of two air force groups with a mixture reconnaissance, anti-air, air to ground, and support capabilities. In addition, a major consideration of the friendly forces will be the enemy's surface-to-surface, and surface to air missile threat. The phase of the operation in which our systems will be evaluated will primarily involve offensive air support and assault support operations. The general description of the enemies capabilities provide the source of targets and threats for our decision aids to be evaluated against. The enemy forces will be simulated on the ground either through the use of static targets or electronic threat emitters. Friendly aviation support, command and control, and air defense forces used in the execution of this scenario will be live. Friendly ground combat forces are represented by one USMC infantry company and one USMC Artillery battery. There will be no notional/simulated friendly aircraft during the execution of the flight phase.

### 3.5 Instrumentation Requirements

Assets required that are outside of those used to conduct the WTI course will be provided by SPAWAR. These requirements are limited to two Laptop computers capable of running the software to be evaluated.

### 3.6 Limitations and Scope of Test

The following subsections and table provides in detail, the scope and limitations of the test to be conducted. A static profile as indicated on the table denotes no actual aircraft being flown. In this instance a simulated air picture will be provided to the command and control agency. A flight profile denotes the use of live aircraft and ordnance used during the evaluation.

#### 3.6.1 Phase I: Pre-Evaluation

Testing will be conducted 2-3 April 2004 to ensure equipment functionality and feasibility of operations. This testing will be conducted within the TACC located at MCAS Yuma. We will also use this phase to record and review initial data.

#### 3.6.2 Phase II: Final Evaluation

Testing will commence on 13 April and conclude on 16 April 2004. This testing will ensure interoperability and evaluate the different decision tool's command and control effectiveness. Ultimately this will provide the basis for our comparative analysis of the two tools and the manual methods currently employed by the decision makers.

**Table 2. T&E Phase Summary**

| Phases | Date | Time | Evolution | Profile |
|---|---|---|---|---|
| **Phase I: Pre-Evaluation** | 2-3 April | TBD | MISTEX | Static |
| **Phase II: Final Evaluation** | 13-16 April | TBD | FINEX | Flight |

## 4.0 Operational Effectiveness

### Test E-1. Target Selection.

**Objective**: To assess whether or not the methods evaluated maintain target priorities when reassigning assets.

**Procedure**: Each target assigned attack assets on the existing ATO have priorities. A target with the priority of one is the highest priority. Each immediate time sensitive or high priority target is also assigned a similar

priority. As each immediate target appears during the exercise the decision aids will be expected to assign assets based on these priorities. If the results reveal that a previously assigned target that is not paired with an asset after running the decision aids has a higher priority than those assigned to assets it will be counted. Operators will annotate on the effectiveness data sheet the number of targets that are of higher priority than those assigned assets.

**Data Analysis**: Accurate target selection will be quantitative in nature. The analysis will be based on the number of higher priority targets that do not have an asset assigned per the total number of assets assigned to targets. Operators will annotate on the data collection sheet (Appendix B) the number of targets with no assets assigned that have a higher priority than the targets assigned assets. During each run of the decision tool the operator will also annotate the number total number assignments that were considered by each decision aid.

**Test E-2. Asset Availability.**

**Objective**: To assess whether or not the methods under evaluation select assets for reassignment that are currently available.

**Procedure**: The operator will record the number of assignments suggested by the decision aid that are unavailable and annotate that on the effectiveness data sheet (Appendix B). For example, assets that have been identified to have mechanical problems, or assets that have already proceeded to assigned targets. This effectiveness test does not take into lack of proper reporting by the exercise force. Regardless of the reason for the decision aids consideration of unavailable assets the operator will annotate the number of erroneous assignments and the total number of assignments. The remarks section on the data sheet will be used to provide reasons for the decision tools assignment if erroneous.

**Data Analysis**: Asset Availability will be assessed quantitatively. A higher ratio of miss-assignments will aid in identifying a system problem in recognition of available assets. The reliability of this measurement will

depend on the timeliness and accuracy of information about current aircraft status. Each method will be compared to determine which has a lower rate of assignment of assets that are not available. A higher rate of assignment of assets not available will help identify a problem with either receiving automated updates or manually updating asset availability.

**Test E-3. Target Asset Pairing.**

**Objective:** To assess whether or not the methods under evaluation properly reassign assets to target that have the ability to meet desired destruction criteria provided by the component commander.

**Procedure:** Each decision aid computes the probability of destruction against a particular target based on the assets ordnance capability. Each decision aid pre-calculates these values. The desired destruction criteria is provided by the destruction criteria matrix developed by the exercise force. Operators will evaluate the number of missions reassigned to the immediate target that have a probability of destruction that is less than the stated destruction criteria. The results will be recorded by either a yes the destruction criteria is met by the results of the decision aid or no it is not on the data collection sheet (Appendix B). Additionally, the destruction level attained by the proposed assignment well be annotated on the data collection sheet.

**Data Analysis:** This measure is quantitative in nature. Each method either automated or manual will be compared to determine which achieves a lower rate of inadequate assignment. The total number of assignments that are below the probability of destruction will be annotated on the data collection sheet. A proposed assignment that does not meet the destruction criteria will indicate either an error in the method for calculating weapons effectiveness against a given target type or lack of availability of assets necessary to destroy a given target. In the case of the latter we will be able to assess the ability of the decision aids to assign assets that can achieve the best results possible.

**Test E-4. Mission Risk Assessment.**

**Objective**: To determine whether or not each method evaluated accurately assesses and takes action to mitigate the risk from associated surface to air threats.

**Procedure**: The proper assessment of risk will be determined post exercise by evaluating each assignment to determine an accurate risk assessment. Operators will maintain a record of each assignment's risk assessment whether that is in the form of a probability aircraft loss or expected value of attrition. Based on this assessment operators will determine if the system or decision maker assigned SEAD assets when available to minimize risk. Operators will annotate risk assessment on the effectiveness data sheet (Appendix B) provided. The assignment of SEAD will be annotated with either a yes or a no on the data collection sheet (Appendix B).

**Data Analysis**: Two elements will be analyzed. First, the number of proper risk assessments for each aircraft will be counted to determine a percentage of proper assessment. Second, a comparative analysis will be conducted to determine which method produced the assignments with minimal risk and assigned SEAD when required. A failure to properly assess risk to aircrew given a surface-to-air threat could point to a problem in the values used in the probability of kill for each threat or a problem in the formulation of risk.

**Test E-5. Persistence.**

**Objective:** To evaluate whether each method attempts to minimize the impact of the reassignment to the current ATO.

**Procedure:** Each ATO can be considered a previously optimized assignment plan. A immediate target necessitates the re-optimization of the ATO. Each method when conducting the reassignment takes steps to insure that as much of the current ATO as possible stays intact while assigning an asset to the immediate target. The number of changes the ATO can be reflected in the number of calls that have to be made to affect the new assignment.

**Data Analysis:** A comparative analysis will be conducted to determine which of the methods effectively minimize the number of changes to the current ATO after conducting the reassignment of assets. Time to act on the proposals provided by the decision aids determines the usefulness of the proposal. Too many changes in a short period of time will indicate a solution, although technically superior, that may not be feasible.

**Test E-6. Timeliness.**

**Objective:** To determine whether or not the methods under evaluation can produce courses of action for the decision maker in a timely enough manner to assist in making a decision.

**Procedure:** Throughout the conduct of the exercise immediate targets will appear that require assignment of assets. At each appearance the operator will annotate on the data collection sheet the time. Target information will be entered into the appropriate system to await results. Once the results are displayed the time will then be annotated on the data collection sheets (Appendix B). From this information we will determine the total time to process the information and make a recommendation to the decision maker. We will then determine the average time for each method.

**Data Analysis:** The analysis is quantitative in nature. Each methods time will be compared to determine the method that can produce results in the shortest period of time. Each failure will be categorized into one of three types: software, hardware, or network failure and annotated on the reliability data collection sheet. (Appendix C)

**Test E-7. Options.**

**Objective:** To evaluate whether the methods provide the decision maker with more than one course of action.

**Procedure:** For each implementation of the decision tools the number of options provided by the decision maker will be counted by the operator and annotated on the data sheet (Appendix B). For every immediate target there exists more than one possible solution.

**Data Analysis:** The average number of options provided by the decision aids will be calculated and compared between each of the methods.

**Test E-8. Tactical Accuracy.**

**Objective:** To evaluate whether or not the output by the automated decision tools provide results that can be considered tactically acceptable. This is one of the primary purposes of the evaluation.

**Procedure:** MAWTS-1 Instructors present during the evaluation will examine each data sheet.

The information on the data sheets represents the proposed solution for each immediate target that presents itself during the exercise. Their comments will be annotated on the effectiveness data sheet provided (Appendix B).

**Data Analysis:** This analysis is subjective in nature. An overall assessment will be made as to the accuracy of the proposed assignments for each individual method.

**5.0 Operational Suitability**

**Test S-1. Software Reliability.**

**Objective**: To determine if the automated tools can operate continuously without interruption throughout the entire tactical evolution.

**Procedure**: The tactical evolutions will run approximately eight hours. During this time the number of system failures will be annotated on the reliability data sheet provided. Each failure will be noted with the time of failure and time of restart.

**Data Analysis**: The analysis is both objective and subjective. Quantitatively we will assess the mean time before failure. Subjectively we will determine if it is a fault of the hardware, software or exercise architecture.

**Test S-2. Interoperability.**

**Objective:** To determine if each system under evaluation is able to electronically receive the ATO.

**Procedure:** Prior to the start of each exercise an ATO will be disseminated by MAWTS-1. The ability to receive the ATO will be identified with either a yes or no on the data sheet.

**Data Analysis:** The assessment will be quantitative in nature. We will assess which method on average is able to receive the ATO. Interoperability problems will be recorded as they occur.

**Test S-3. Human Factors.**

**Objective:** Can the display be easily interpreted with respect to its inputs and outputs?

**Procedure:** Using the suitability questionnaire a perception of how well the interface display for each system explains the results to the user. Each aspect identified in the data requirements will be assessed.

**Data Analysis:** The analysis is subjective in nature. Each method will be assessed individually to determine usability.

## LOGISTICS AND SUPPORT REQUIREMENTS

**1.0** MAWTS-1 PERSONNEL REQUIREMENTS

**1.1** Aviation Development, Tactics, and Evaluation (ADT&E) Department

**1.1.1** Coordinating Officer

Coordinate the efforts of all T&E participants throughout the duration of the T&E process.

Co-develop T&E plan.

Co-develop operator checklists and questionnaires.

Provide assistance in developing the T&E final report.

**1,1,2** Aviation Operations Analyst

Provide analytical assistance to support the T&E.

Provide assistance to the Project Action Officer in writing the final report.

**1.2** Command, Control, and Communications (C3) Department

**1.2.1** Project Action Officer

Coordinate the efforts of all T&E participants throughout the duration of the QA process.

Co-develop the T&E plan.

Co-develop aircrew and operator checklists and questionnaires.

Supervise administering and collection of surveys.

Co-develop T&E final report.

Table 2 details project milestones.

**Table 3. Project Milestones**

| Milestone | Date | Responsible Agency |
|---|---|---|
| T&E Phase I | 2-3 April 04 | NPS |
| T&E Phase II | 13-16 April 04 | NPS |
| Interim T&E Message | ????? | MAWTS-1 |
| Final Report | 1 May 04 | MAWTS-1 |
| | | |

**2.2 Personnel Assignment**

Personnel assigned to this T&E are listed in Table 3.

**Table 4. T&E Personnel**

| Rank | Name | Billet | E-mail | Fax (DSN) | Phone (DSN) |
|---|---|---|---|---|---|
| Maj | Weaver, P.R. | Project Action Officer | prweaver@nps.navy.mil | | 756-2786 |
| Maj | Doty, C. R. | Coordinating Officer | dotycr@mawts1.usmc.mil | 269-2637 | 269-3681 |
| Maj | Mowery, S. P. | Aviation Ops Analyst | mowerysp@mawts1.usmc.mil | 269-2637 | 269-2684 |

## 3.0 Reports

The results of this T&E will not be released until the final report is signed by the MAWTS-1 Commanding Officer.

## 4.0 Project Security

This T&E is UNCLASSIFIED FOUO.

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# APPENDIX B: POST EVENT QUESTIONNAIRE

UNITED STATES MARINE CORPS
MARINE AVIATION WEAPONS AND TACTICS SQUADRON ONE
BOX 99200
YUMA, AZ 85369-9200

**TACTICAL EVALUATION OF OPTIMIZATION METHODS USED IN NEAR REAL TIME RETARGETING OF AVIATION ASSETS**

March 2004

## Annex B: Questionnaires and Data Sheets (TO be filled out by participant)

**Background.** This is a Test and Evaluation (T&E) for the use of the Rapid Asset Pairing Tool (RAPT) and NPS Tool.

**Instructions.** This survey is divided into two sections that will evaluate RAPT:

(1) Effectiveness

(2) Suitability

### I. Background Information

Age: _____ Rank (i.e. O-3): _____ Service (i.e. USMC): ________ Years of Service: _____

Designations Held:
______________________________________________________________

**Questionnaire**

Date__________________

Evolution ______

**Tool Assessed:** **RAPT** **NPS (Circle One)**

**TST#__________**

Target Type__________Target Priority__________

**COI #6 Timeliness**

Time Received __________ Time Output received (automated tool)__________

Time DM determined option without automated tool_______ Time DM assigns Asset __________

***Remarks***__________________________________________________________

**COI#1 Target Selection**

Number of targets not assigned assets that are a higher priority than those assigned assets.

NPS/RAPT __________ DM___________ Total Number of assets assigned___________

***Remarks***__________________________________________________________

__________________________________________________________

**COI#2 Asset Availability**

Number of assets assigned that are available based on current situation.

RAPT/NPS___________ DM__________

Total assets assigned__________

***Remarks***__________________________________________________________

__________________________________________________________

**COI#3 Target Asset Pairing**

Number of assets assigned that meet destruction criteria.

RAPT/NPS__________ DM__________ % Assigned by NPS/RAPT____________

Total assets assigned_________ % Assigned by DM____________________

**COI#4 Mission Risk Assessment**

Risk assessment to aircraft reassigned

NPS/RAPT _____________ Prob of losing aircraft/expected value of attrition

SEAD required YES NO

SEAD recommended by NPS/RAPT YES NO

SEAD used by DM YES NO

***Remarks***________________________________________________________________________

________________________________________________________________________________

______________________________

**COI#5 Persistence**

Number of changes to ATO using RAPT/NPS__________________

Number of changes to ATO required by DM actions __________________

Number of missions cancelled based on reassignment by RAPT/NPS______________.

Number of missions cancelled based on reassignment by RAPT/NPS______________.

***Remarks***________________________________________________________________________

________________________________________________________________________________

______________________________

**COI#7 Options**

Number of reassignment options provided NPS/RAPT__________________

Number of reassignment options provided by DM______________________

***Remarks***________________________________________________________________________

________________________________________________________________________________

______________________________

**COI#8 Tactical Accuracy**

**WAS THE RECOMMENDED ASSIGNMENT TACTICALLY ACCEPTABLE? YESNO**

***Remarks***__________________________________________________________________

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## APPENDIX C: POST EVENT QUESTIONNAIRE


UNITED STATES MARINE CORPS
MARINE AVIATION WEAPONS AND TACTICS SQUADRON ONE
BOX 99200
YUMA, AZ 85369-9200


# DECISION AIDS FOR DYNAMIC RETASKING OF AVIATION ASSETS
# POST EVENT QUESTIONNAIRE


Maj P.R. Weaver, USMC
Operations Research Department, Naval Postgraduate School
DSN 269-2957  COM (928) 269-2957

Maj S. P. Mowery, USMC
ADT&E Department
DSN 269-2684  COM (928) 269-2684


DECEMBER 2003

**Background.** Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) is conducting a Tactical Demonstration (TACDEMO) of Decision Aids for Dynamic Re-tasking of Aviation Assets. To be filled out by participant.

**Instructions.** This survey is divided into two sections that will assess the effectiveness of various decision aids in support of aviation assets conducting time sensitive targeting:

(3) Operability/Reliability

(4) Human Factors

## II. Background Information

Age: _____ Rank (i.e. O-3): _____ Service (i.e. USMC): ______Years of Service: _____

Designations Held: ________________________________________________________
(SAC, SWO, SWO, DBC)

Number of WTI operations participated in: _____

**<u>Operability/Reliability.</u>** Using the scale below, rate each statement by circling one corresponding number. Please include comments if you have suggestions for improvements. Based on your experience, describe your **level of agreement** with the statement that:

1.) RAPT/NPS was able to receive the ATO correctly from TBMCS. 1 2 3 4 5 6 7

***Comments***:______________________________________________________________________________

2.) RAPT/NPS functioned without interruption 1 2 3 4 5 6 7

Time interruption occurred____ Time interruption ended____
Number of interruptions______
***Comments***:______________________________________________________________________________

General comments on RAPT effectiveness in increasing command, control and situational awareness.

__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

**Reliability Data Sheet (To be filled out by system operator for each error)**

**Failure Number________**

**Time Failure Occurred________**

**Time System Repaired_______-**

**Type of Failure (Circle One) Software Hardware Network**

**Reason and Impact of Failure**

**To be filled out by participant: (Circle One) RAPT NPS Decision Aid**

---

**<u>Human Factors.</u>** Using the scale below, rate each statement by circling one corresponding number. Please include comments if you have suggestions for improvements. The following questions have to do solely with the ease of understanding the display information for the RAPT/NPS tools. Based on your experience, describe your **level of agreement** with the statement that:

| | STRONGLY AGREE | | | STRONGLY | | DISAGREE | |
|---|---|---|---|---|---|---|---|
| 1.) Probability of destruction was easy to interpret. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

***Comments***:______________________________________________

2.) Risk Assessment was easy to interpret. 1 2 3 4 5 6 7

***Comments***:______________________________________________

3.) Persistence was easy to interpret. 1 2 3 4 5 6 7

***Comments***:______________________________________________

4.) Current Mission number was displayed accurately. 1 2 3 4 5 6 7

***Comments***:______________________________________________

5.) Target information was easy to interpret. 1 2 3 4 5 6 7

***Comments***:______________________________________________

6.) Target priority was easy to interpret. 1 2 3 4 5 6 7

***Comments***:______________________________________________

6.) Associated threat information was easy to interpret. 1 2 3 4 5 6 7

***Comments***:______________________________________________

**General comments on the ease of interpreting the current display information:**

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